COMPUTER AIDED STRIP-LAYOUT AND BLANKING DIE DESIGN

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by

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CERTIFICATE

This is to certify that the work entitled, "Computer
Design
Aided Strip Layout and Blanking Die," has been carried out by Shri Radhakrishna, K.R., under my supervision and has not been submitted elsewhere for the award of a degree.

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LIST OF FIGURES

LIST OF SYMBOLS

A	-	Area of component in mm^2.
B	-	Bridge width in mm.
C	-	Pitch in mm.
C_p	-	Punch clearance in mm.
d	-	Horizontal distance.
e	-	y-intercept of a straight line.
f	-	x-intercept of a straight line
F	-	Force in Newtons.
H	-	Width of the Component in mm.
I_c	-	Code to identify type of segment.
l_d	-	Die length in mm.
m	-	Slope
N	-	Number of vertices or number of segments.
P	-	Perimeter of the component in mm.
r	-	Radius in mm.
S	-	Sheet width in mm.
t	-	Sheet thickness in mm.
t_d	-	Die thickness in mm.
u	-	Area utilisation.
u_o	-	Overall area utilisation.
u_s	-	Ultimate shear strength in N/mm^2.
W	-	Width of the strip in mm.
w_d	-	Width of die block in mm.
$\bar{X}$, $\bar{Y}$	-	Center of pressure coordinates.
$\bar{x}$, $\bar{y}$	-	Center of gravity coordinates.
$\forall$	-	For all.

COMPUTER AIDED DESIGN OF LAYOUT AND DESIGN OF BLANKING DIE

ABSTRACT

In the present work, algorithms have been developed to carryout computer aided strip layout and die design of sheet metal parts involving blanking operation.

The strip layout problem is treated considering the various design requirements such as minimisation of scrap, maximising the strength of parts when subsequent bending is involved and production environment factors such as type (coiled or strip) and width of stock available.

Algorithms are proposed for strip layout of a single component that can be represented by a series of points on its contour (Polygon). Further, a new approach is developed for the determination of strip layout parameters such as width, pitch and component area for a component with circular arcs as part of its contour. The component is represented as a series of segments (circular or straight line) rather than as a series of points and the geometrical properties of the segments are used in determination of the above parameters. The algorithms are developed to implement conventional die design of a simple blanking die for a polygon shaped component.

The strip layout and die design have been integrated by implementing the respective algorithms into an interactive package. The algorithms are tested with typical examples.

The new approach of component representation can be applied to die design problem also. Further, suitable NC program interface with the above package can be developed which will automate the manufacture of punch and die.

LIST OF SYMBOLS

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$\overline{X}, \overline{Y}$	-	Center of pressure coordinates.
$\bar{x}, \bar{y}$	-	Center of gravity coordinates.
$\forall$	-	For all.
x'', y''	-	Coordinates in new orientation.
x', y'	-	Intermediate coordinate values.

CHAPTER I

INTRODUCTION AND LITERATURE SURVEY

1.1 Introduction:

Sheet metal working has applications in wide range of industries from electronics to automobile industries. Sheet metal components are used as load carrying structures (as in case of automobile body), support structures (as in case of electronic instruments and computers), protective covers (covers for belt drives), laminations (transformers and other electrical machines), utility products (utensils) etc.

Production of sheet metal components involve s any one or a combination of operations such as blanking, punching bending, drawing etc. Depending upon production environment and part complexity, a plan of operations is decided. By its very nature, blanking finds itself as a the? first operation. For some components such as rotor stampings the blanking operation produces the final component.

1.11 Factors in Layout and Die Design for Blanking:

The layout design affects the raw material cost which generally forms a large part of the total cost of sheet metal components. The conventional design of layout is done by

arranging the templates of blanks in different orientations so as to reduce the wastage of material. The die design for blanking and tooling cost depend on the selected layout. The other factor which will influence the layout and hence die design is the availability of the press of required tonnage. All these factors are to be taken into consideration while designing a blanking die.

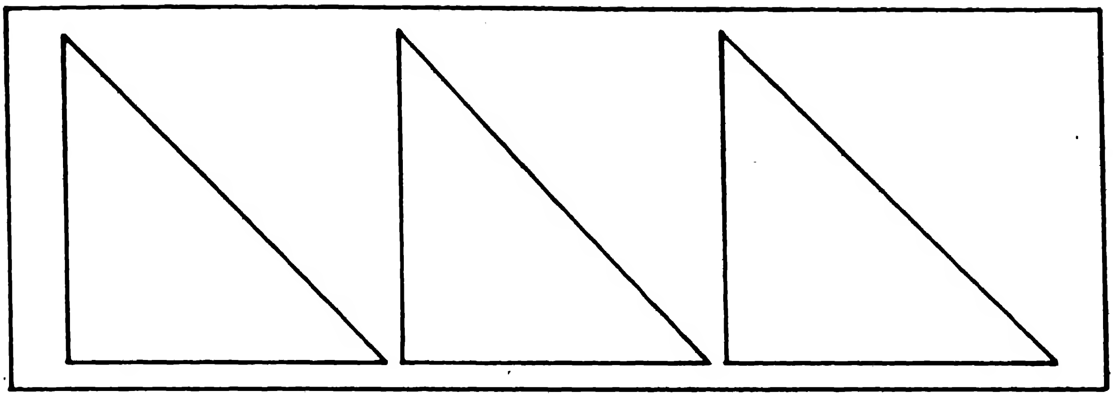
1.12 Classification of Layout Problem:

The layout problem can be classified on the basis of number of different components to be considered. The two types of problems are (i) single-component problem and (ii) multiple-component problem .

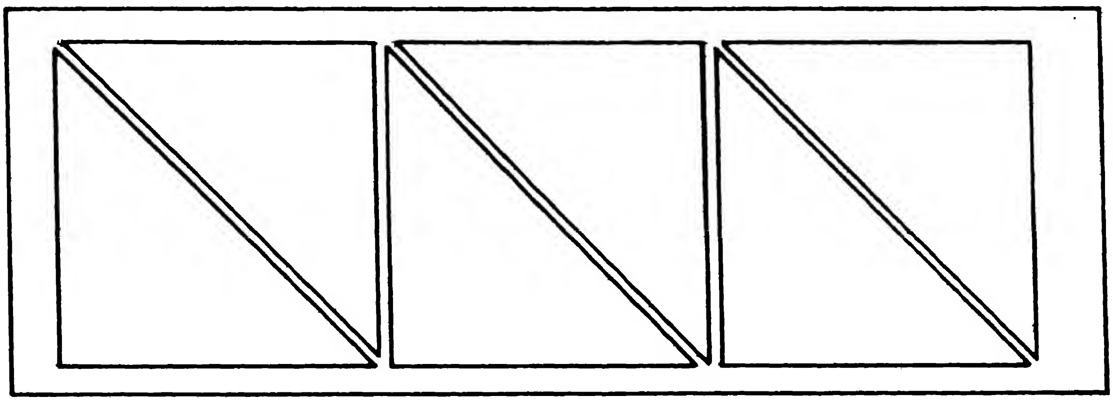
The single-component problem involves arrangement of a single shape on a strip so as to minimise wastage. It may be a single row, double row or a multiple row layout as illustrated in Fig. 1. A multiple-component problem involves arrangement of a given number of different shapes on a strip as shown in Fig. 2.

1.13 Conventional Die Design for Blanking:

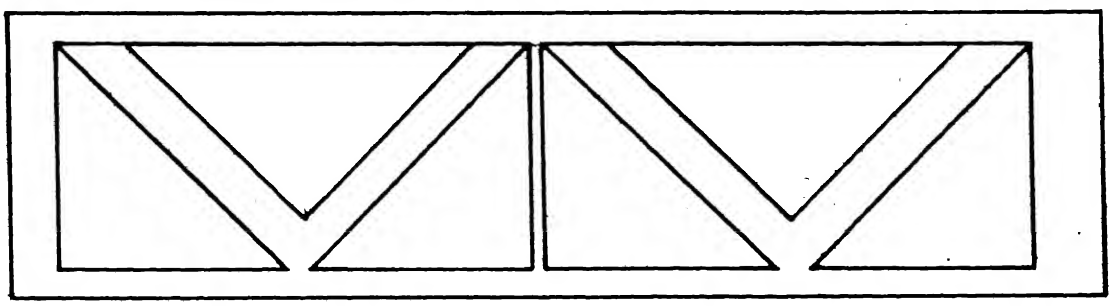
It involves design of scrap strip layout, design of die and punch, design of other elements such as stripper plate, stop pin, dowels, capscrews etc. and selection of die set and suitable press. The design procedure is evolved through experience and trial and error and is based on several empirical considerations.



SINGLE ROW LAYOUT



DOUBLE ROW LAYOUT



TRIPLE ROW LAYOUT

Fig. 1 TYPES OF SINGLE COMPONENT LAYOUT.

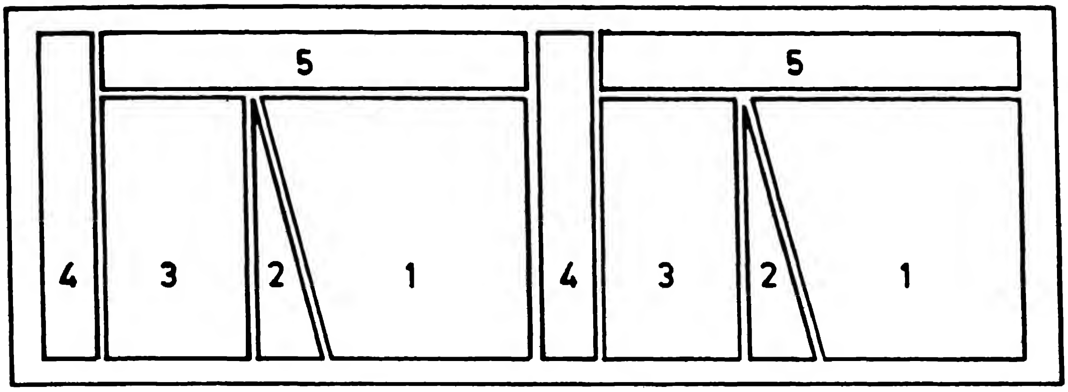


FIG. 2 MULTIPLE COMPONENT LAYOUT

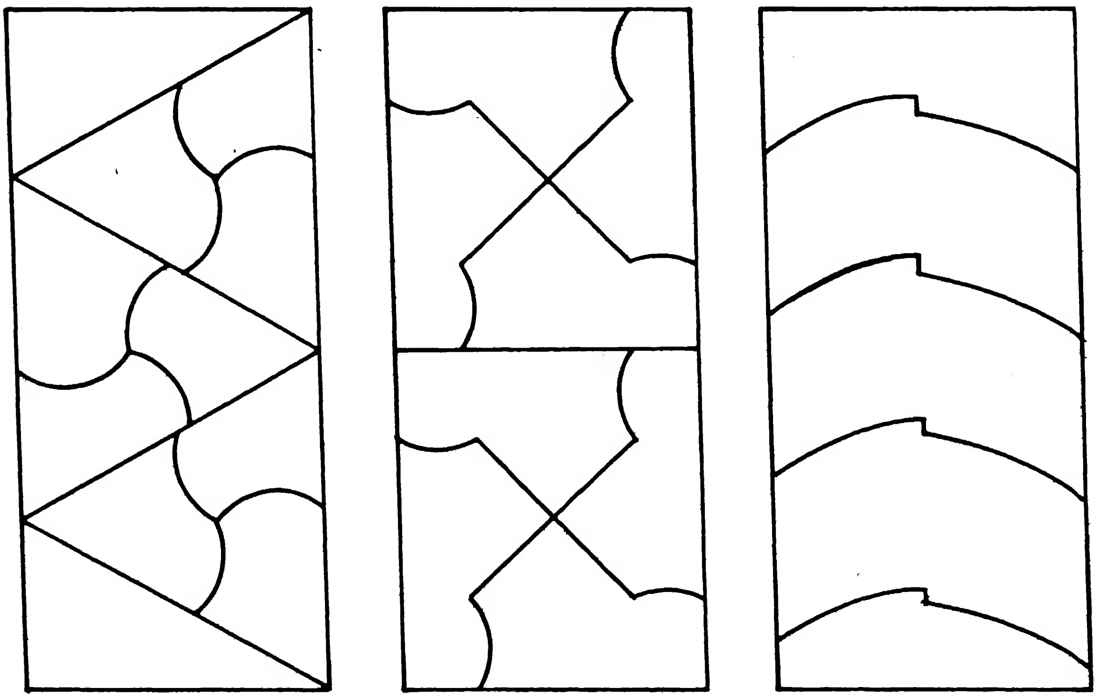


FIG. 3 DIFFERENT TYPES OF INTERLOCKING SHAPES.

1.2 Literature Survey:

Literature on optimal layout problem is reviewed considering the two types of problems defined in Section 1.1.

Chow [1] suggested a solution to the single component problem. He pointed out that many of the two dimensional components are of symmetrical shape and it may be possible to generate inter locking shapes for arriving at a scrap free layout. [Fig. 3]. He suggested the approximation of other shapes into such symmetrical shapes. Cnee [2] gave a blank layout solution for a component that can be represented as a polygon. His solution involved single-row and double-row layouts. The optimum orientation was arrived at by testing different orientations. The sheet width constraint was taken into account considering slitting losses and left overs at the end.

The multiple component problem was handled as a two-dimensional nesting problem by Admowicz and Albano [3]. They proposed that irregularly shaped components or their clusters should be enclosed in minimum area rectangles. Further, such rectangular modules were arranged on a strip so as to minimise the wastage. The problem of arranging the rectangular modules in a standard size rectangular sheet was dealt by Albano and Orsini [4]. A heuristic approach was used to reduce it to one dimensional problem which was then solved

as a knapsack problem, by dynamic programming. Prasad and Dhande [5] developed a package to generate nesting of two-dimensional shapes. State space search approach involving largest area and longest perimeter as a criterion was used for arriving at a rectangular module and dynamic programming was used to arrive at the optimal layout.

The literature on multiple component problem mostly deals with the problem from area utilisation consideration only. Cnee's [2] compared alternative layouts by considering die costs.

The die design for blanking is evolved through experience and is based on several empirical considerations. However, the procedure laid down in Die Design Hand Book [6] and Tool Design Hand Book [7] is widely accepted. Donaldson [8] also treats the blanking die design problem in a similar way although the die thickness calculation procedure is slightly different. Die Design and Die Making Practice [9] also deals with the die design problem for blanking and illustrates different types of punch supports, ejectors and stop pins.

The problems of strip layout and die design have been treated separately in the literature. However, the two problems are closely interlinked and optimum designs can be obtained by integrating the strip layout and die design.

1.3 Scope of Present Work:

It is intended to develop algorithms for the design of single row and pairwise layouts, and the design of a blanking die. The aim is to implement and test the above algorithms and develop a user-friendly interactive program which will enable the die designer to get an optimum layout and the corresponding blanking die details.

CHAPTER II

LAYOUT AND DIE DESIGN FOR BLANKING

2.1 Introduction:

The methodology of designing a satisfactory layout (single row or pair-wise) and the corresponding blanking die is described in this chapter. Section 2.2 describes the considerations involved in layout design and strategies for handling the same.

The methodology of designing a blanking die is described in Section 2.3.

2.2 Optimum Layout:

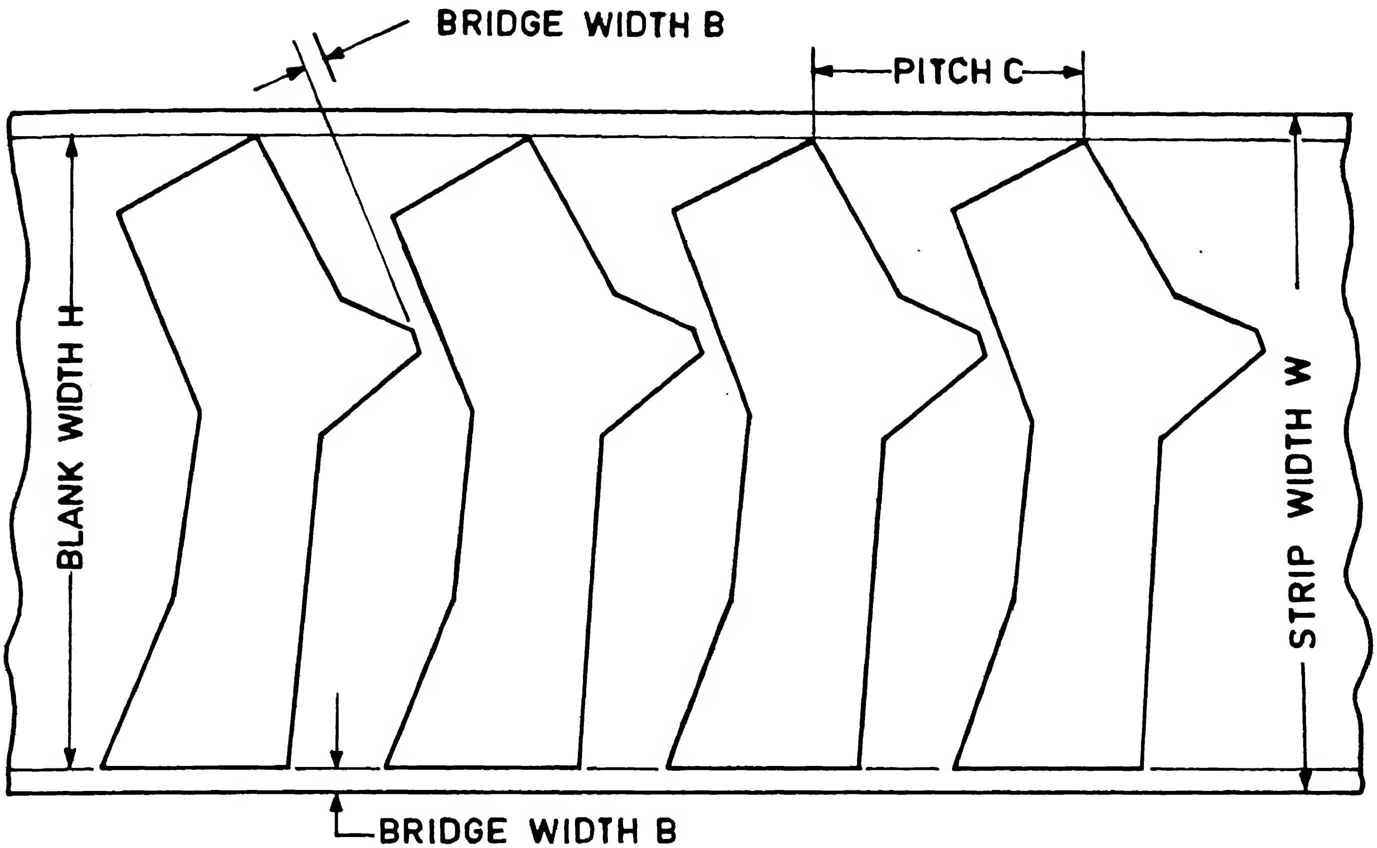
2.21 Terminology for Layout Design:

The terminology used to describe the layout problem is illustrated in Fig. 4.

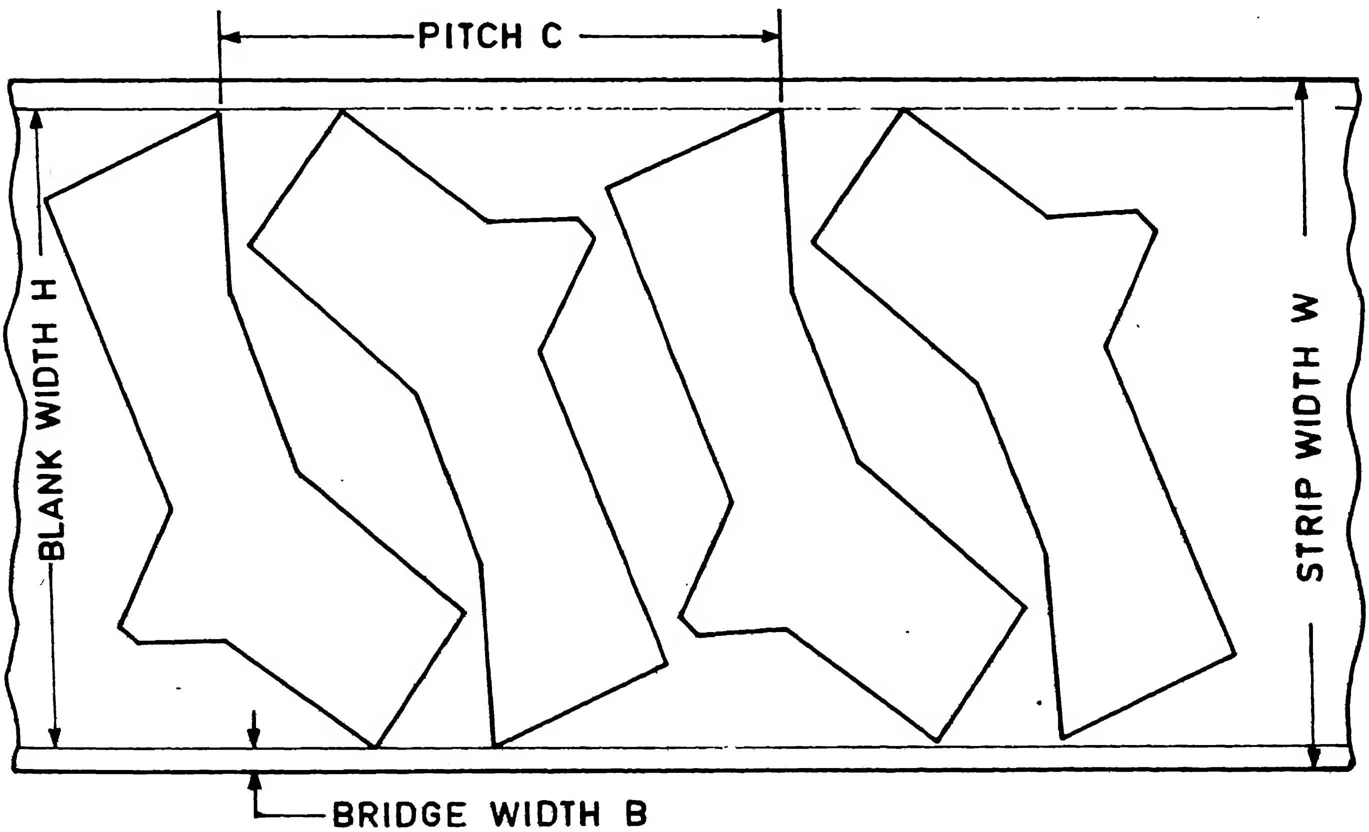
Blank Width H: Difference between maximum and minimum y-coordinates of a blank, when laid out on a strip.

Pitch C: Difference between the x-coordinates of any two successive points when the blanks are laid out on the strip.

Bridge Width B: Minimum distance between the two successive blanks or the blank and the edge of the strip.



SINGLE ROW LAYOUT



PAIRWISE LAYOUT

FIG. 4 TERMINOLOGY FOR LAYOUT DESIGN.

Strip Width W: Width of the strip on which blanks are laid out and is given by,

$$W = H + 2B \tag{2.1}$$

Sheet Width S: It is the width of standard sized sheets which are slit into strips of suitable width.

Area Utilisation u: Ratio of blank area to area of strip consumed for producing one blank.

$$u = \frac{A}{CH} \times 100 \tag{2.2}$$

Overall Area Utilisation u_o: Ratio of blank area to the area of sheet consumed for producing one blank and is given by,

$$u_o = \frac{WM}{S} \times u \tag{2.3}$$

where M is the number of strips of width W that can be slit from the sheet of width S.

2.22 Strip Layout Considerations:

The following considerations are important for arriving at a satisfactory layout.

(i) The layout must be arranged so as to minimise the wastage of material. The material costs constitute a large part of the total cost of sheet metal product. Hence even a small saving of stock will result in substantial reduction in cost.

(ii) The grain direction of strip is an important consideration in the layout of blank when a subsequent bending operation is required. Sheet metal rolling results in elongation of grains in the direction of rolling. To obtain maximum strength of parts, the bends should be made at an angle of 90° to the rolling direction. The normal grain direction of a coiled strip is parallel to the edge of the strip. When stock-strips are sheared from sheet stocks, it is possible that the grain direction is either parallel or at 90° to the edge of the strip, depending upon the orientation of shearing operation.

(iii) The effect of blank layout solution on the die design needs to be evaluated. The need to coincide the centre of pressure with the axis of the press ram affects size of the die block for different blank orientations. The selection of single row layout leads to the design of a simple blanking die. For pairwise layout a double pass operation is needed if strip stock is used. If coiled stock is used, two sets of punch and die have to be employed as it is not practical to recoil a partially blanked coiled stock and pass it through the die opening second time.

(iv) It is necessary to consider the spacing, B between blanks. Blanks located too close together or, too close to the edge of the strip tend to allow the metal to slip by the

cutting edges of the punch and die. The web between the blanks that form the scrap skeleton must he strong enough to withstand the feeding force. A general thumb rule is to make the web between the blanks and edge of the strip atleast $1\frac{1}{2}$ times the strip thickness. However, web thickness may be varied depending upon the thickness of strip, the hardness of material, the length of scrap web, the shape of workpiece and the type of operation [8].

2.23 Strategies for Strip Layout:

In this section strategies to handle any combination of the above considerations are presented. The following cases describe the different possible situations in layout design.

Case I: Either subsequent bending of the blank is not involved or its effect is not important. The component is rotated in steps from 0-180° and the area utilisation is determined in each case. Based on whether sheet width is specified or not, it is subdivided into the following two cases.

(a) The sheet width is not specified: In this case, there are two situations depending on the type of stock used.

(i) If strip stock is used, then the selection between single-row and pairwise layout is based on area utilisation consideration only.

(ii) If coiled stock is to be used the selection of pairwise layout means the use of two pairs of dies and punches. Hence

if pair-wise layout is to be selected the cost of additional tooling involved should be compared with the savings of raw material.

(b) The sheet width is specified: In this case, over all area utilisation u_o rather than area utilisation u should be used as a criterion for both the cases (i) and (ii) as in (a) above.

Case II: Subsequent bending of blank is involved and it requires that the bending direction be oriented at 90° to the grain direction. In this case the orientation of the blank will be fixed.

Case III: Subsequent bending of blank is involved and it allows a limited range of orientations. In this case the area utilisation is calculated for different orientations within this range and the selection of layout is similar to the procedure described for Case I.

Case IV: In this case either more than one bend direction is to be taken into account or sheet width happens to limit some of the possible orientations. The best solution can be chosen from the following graphs:

1) area utilisation vs. width
2) area utilisation vs. orientation
3) width vs. orientation

These three graphs are hereafter referred to as variation graphs.

2.3 Blanking Die Design:

The design procedure described in this section is based on the procedure given in [7].

2.31 Components of a Simple Blanking Die:

A simple blanking die is shown in Fig. 5. The die-set is fastened to the bolster plate by bolts and nuts. The die block is fastened to the die holder by capscrews and dowels. The stripper plate having a channel for the stock is fastened to the die block. The punch is fastened to the punch holder by various means [7]. Guide pins serve to maintain accurate alignment between die and punch.

2.32 Design of Die Block:

The overall dimensions of the die block are determined from die wall thickness and the space needed for mounting screws and dowels. Die wall thickness depends on the thickness and the strength of stock to be cut. Sharp corners in contour may lead to cracking in heat treatment and so require greater wall thickness. In practice, the die thickness should never be less than 25 mm. There are two methods of design of die block.

Method 1: Thumb rule for design of die block:

The die is assumed to be made of tool steel and the die thickness is directly related to the blanking perimeter.

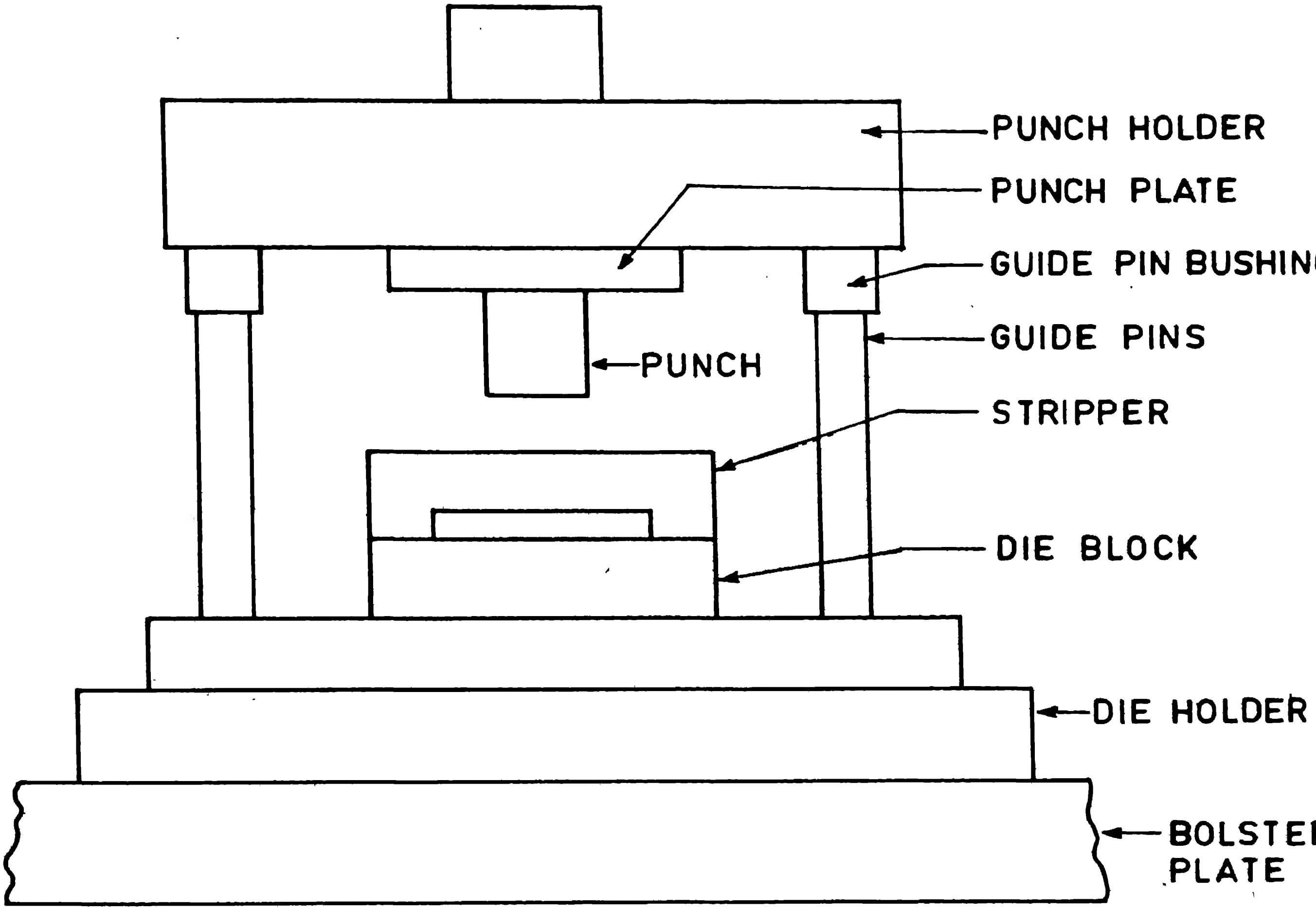


FIG. 5 COMPONENTS OF A SIMPLE BLANKING DIE.

In case of mild steel strip the die thickness is determined from the following table:

Blanking perimeter in mm	Upto 75	75-250	Over 250
Die thickness in mm	20	25	32

The minimum margin around the die opening should be 32 mm. A grinding allowance of 3 mm should be added to the die thickness.

Method II: Alternative method for design of Die Block:

This method of calculating the proper size of the die was derived from a series of tests whereby die plates were made increasingly thinner until breakage became excessive. From these data the calculation of die thickness was divided into four steps.

(i) The die thickness is provisionally selected from Table A (Appendix I). This table takes into account the thickness of stock and its ultimate shear strength.

(ii) The following corrections are made.

(a) The die must never be thinner than 10 mm.

(b) Data in Table A apply to small dies i.e., those with a cutting perimeter of 50 mm or less. For larger dies the thickness listed in Table A must be multiplied by a factor in Table B.

(c) Data in Tables A and B is for dies made of tool steel properly machined and heat treated. If a special alloy of steel is selected, die thickness can be decreased.

(d) Dies must be adequately supported on a flat piece.

(e) A grinding allowance of 3 to 5 mm must be added to the calculated die thickness.

(iii) The critical distance between the cutting edge and the die border must be determined. In small dies, it is equal to 1.5 to 2 times the die thickness and in larger dies, it is 2 to 3 times the die thickness.

(iv) Finally the die thickness must be checked against the empirical rule that the cross sectional area between die opening and its edge must bear a certain minimum relationship to the impact pressure, F for a die put on a flat base. The impact pressure is given by,

$$F = P\, u_s\, t \qquad (2.4)$$

If the die thickness as calculated by steps 1 and 2 above does not satisfy this requirement, it must be suitably increased.

2.33 Die Opening and Draft:

The die opening should be straight for a maximum of 3 mm. The opening should then taper out at 1/4 to $1\frac{1}{2}^{\circ}$ to the sides (draft). The straight portion provides for resharpening of the die. The tapered portion enables the blanks to drop through without jamming.

2.34 Design of Punch:

The punch design involves the calculation of punch contour coordinates after applying the desired clearance. The punch clearance depends on the thickness and the hardness of the sheet material. But there is considerable variation in the amount of clearance to be specified [8]. Hence, in the present work, the clearance is specified interactively. The punch height is decided by the sheet height of the press and die thickness.

2.35 Selection of Die Set and Press:

The available surface area for mounting the punch and die components is called the die area. The die set is so selected that the die area on the die shoe is atleast 6 mm larger, all around the die block. Many different sizes and styles, of standard die sets, are listed in the manufacturer's catalogues [10], but the most frequently used style is the rear pillar rectangular die set [8]. The dimensions of cast iron rear pillar rectangular victor die set, given in Table C are used.

The selection of press is based on punch force and availability. Different types of presses such as hydraulic transfer, horn, straight-slide, open back inclinable (OBI) presses are in use. But in this work, it is assumed that OBI presses are used and the press data is listed in Table D.

2.36 Design of Stripper Plate and Stop Pin:

There are two types of strippers, viz. (i) fixed and (ii) spring operated. In this work, for designing simple blanking die, fixed stripper plate is used. The stripper has the same width and length as the die block. The channel width is given by the following expression,

$$W_c = W + 2t \qquad (2.5)$$

The stop pin has a diameter of 3 times the sheet thickness and protrudes above the die block, upto a height of 1.5 times the sheet thickness. The height of the stock strip channel is 3 times the sheet thickness.

CHAPTER III

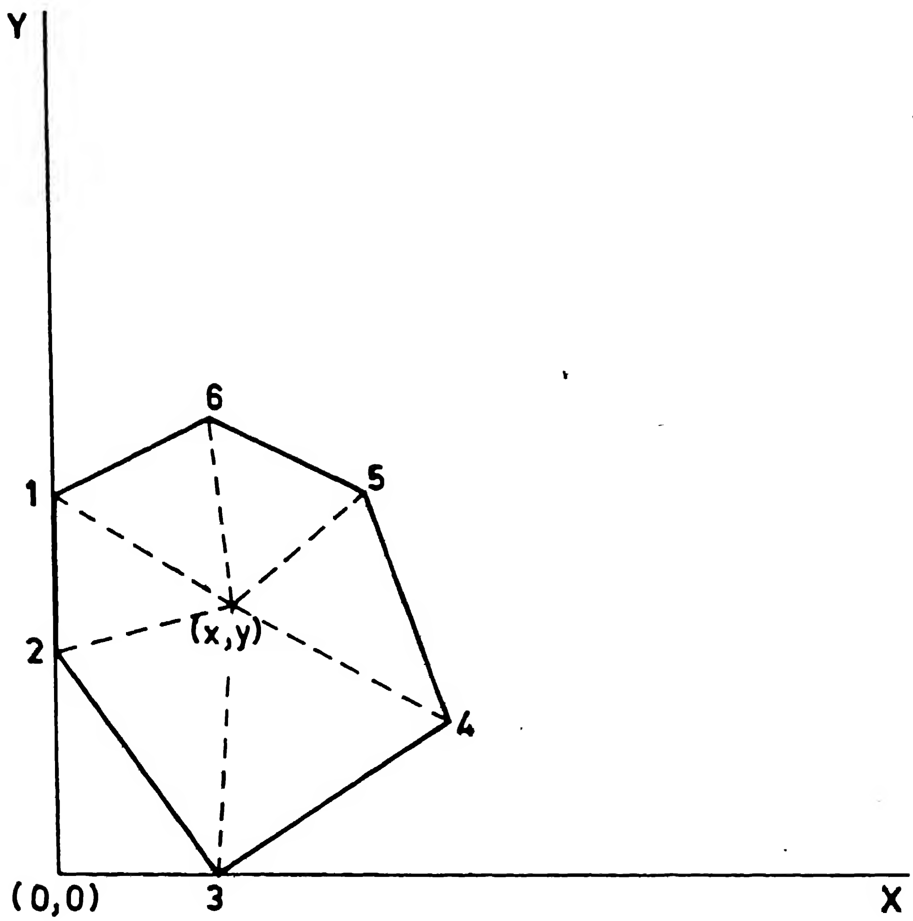
ALGORITHMS IN LAYOUT DESIGN OF POLYGON SHAPED COMPONENT

The algorithms involved in the layout design of a component whose contour can be represented as a polygon, are elaborated. Section 3.1 describes the representation of the component in different orientations, and area calculation. Section 3.2 describes the calculation of width and pitch for a given orientation. Section 3.3 gives the calculation of area utilisation u and overall area utilisation u_o.

3.1 Representation of Component and Area Calculation:

The component is represented as a polygon (Fig. 6) which is defined by the x and y coordinates of all its vertices. The component in any other orientation θ, is represented in a similar manner by calculating x and y coordinates using the following expressions.

$$\begin{aligned} x'_i &= x_i \cos\theta - y_i \sin\theta \\ y'_i &= y_i \cos\theta + x_i \sin\theta \\ x''_i &= x'_i - \min(x'_i) \\ y''_i &= y'_i - \min(y'_i) \end{aligned} \qquad i \;\forall\; 1,N \qquad (3.1)$$



VERTEX	X COORDINATE	Y COORDINATE
1	0	50
2	0	30
3	20	0
4	50	20
5	40	50
6	20	60

FIG. 6 REPRESENTATION OF A COMPONENT AS A POLYGON.

where, N is the number of vertices.

The area of the polygon is calculated by determining the center of gravity of the area as follows.

$$\bar{x} = \sum_{i=1}^{N} \frac{x_i}{N}$$
$$\bar{y} = \sum_{i=1}^{N} \frac{y_i}{N} \qquad (3.2)$$

All vertices of the polygon are joined to the point $(\bar{x}, \bar{y})$ by straight lines as shown in Fig 6. The area of the polygon is given by,

$$A = \sum_{i=1}^{N} \frac{1}{2} \begin{vmatrix} 1 & 1 & 1 \\ x_i & x_{i+1} & \bar{x} \\ y_i & y_{i+1} & \bar{y} \end{vmatrix} \qquad i \forall 1,N \qquad (3.3)$$

when $i+1 = N+1, \quad i+1 \Rightarrow 1$

3.2 Width and Pitch Calculation:

3.21 Determination of Width:

The width H is calculated by taking the difference of maximum and minimum of all y coordinates,

$$H = \max(y_i) - \min(y_i) \qquad i \forall 1, N \qquad (3.4)$$

The width calculated by eqn. (3.4) is applicable for both single-row and pairwise layouts.

3.22 Determination of Pitch for Single Row Layout:

Pitch C is defined as the maximum of horizontal length HL_i of all the verticies (Fig. 7).

Horizontal length HL_i of a vertex i is the longest of distances from the vertex to the points of inter-section, that a horizontal drawn from the vertex makes with the sides of the polygon.

The horizontal lengths HL_i are determined from the following expressions.

When,

$$\left.\begin{array}{l} y_j \leq y_i \leq y_{j+1} \\ \text{or} \quad y_{j+1} \leq y_i \leq y_j \end{array}\right\} i \;\forall\; 1,N \text{ and } j \;\forall\; i+1,\; N+i-2$$

$$\text{when} \quad j > N, \quad j \Rightarrow j-N \tag{3.5}$$

$$(HL)_i = \max |(x_i - x_p)| \quad i \;\forall\; 1,N \text{ and } p \;\forall\; 1,K$$

where,

$$x_p = \frac{(y_i - e_j)}{m_j}$$

$$K = \text{Number of points of inter section}$$

$$e_j = y_j - m_j x_j, \quad m_j = \frac{(y_{j+1} - y_j)}{(x_{j+1} - x_j)}$$

Hence pitch C is given by,

$$C = \max (HL_i) \quad i \;\forall\; 1,N \tag{3.6}$$

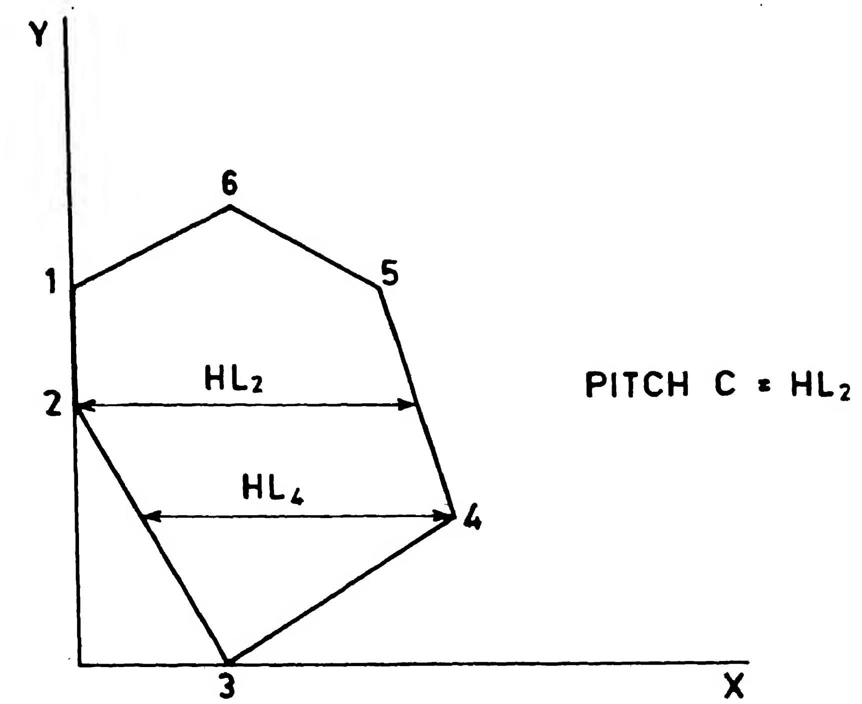


FIG. 7 ILLUSTRATION OF TERMINOLOGY FOR CALCULATION OF PITCH FOR SINGLE ROW LAYOUT.

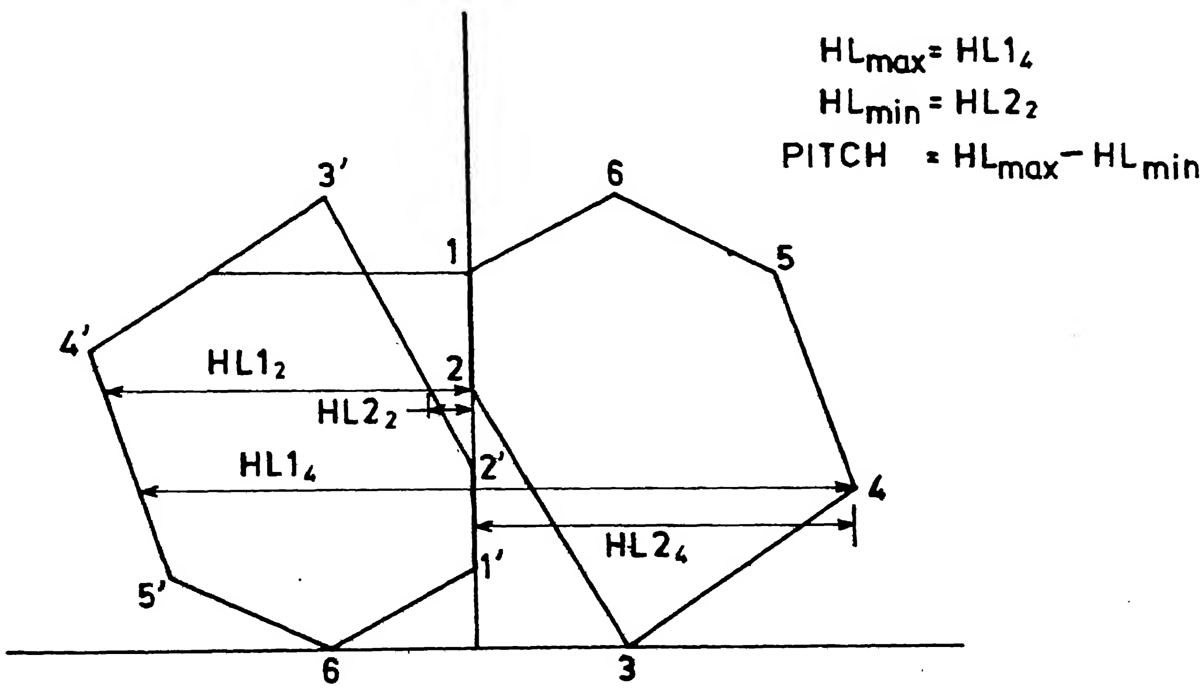


FIG. 8 ILLUSTRATION OF TERMINOLOGY FOR CALCULATION OF PITCH FOR PAIRWISE LAYOUT

3.23 Determination of Pitch for a Pairwise Layout:

The coordinates of the component at any orientation θ are given by,

$$
\left.
\begin{aligned}
xl'_i &= x_i \cos\theta - y_i \sin\theta \\
yl'_i &= y_i \cos\theta + x_i \sin\theta \\
xl_i &= xl'_i - \min(xl'_i) \\
yl_i &= yl'_i - \min(yl'_i)
\end{aligned}
\right\} \quad i \forall 1,N \qquad (3.7a)
$$

The coordinates of the pair are given by,

$$
\begin{aligned}
x2_i &= -xl_i + HL_{min} \\
y2_i &= -yl_i - \min(yl_i)
\end{aligned} \qquad (3.7b)
$$

The minimum and maximum horizontal distance between the component and its pair HL_{min}, HL_{max} are calculated by the following expressions (Fig. 8).

When,

$$
\left.
\begin{aligned}
& y_j \le y_i \le y_{j+1} \\
\text{or} \quad & y_{j+1} \le y_i \le y_j
\end{aligned}
\right\} \quad i \forall 1,N \text{ and } j \forall 1,N \qquad (3.8)
$$

$$
\begin{aligned}
(HL1)_i &= \max |(xl_i - x_p)| \\
(HL2)_i &= \min |(xl_i - x_p)|
\end{aligned} \quad i \forall 1,N \text{ and } p \forall 1,K
$$

where K is number of points of intersection.

$$x_p = \frac{y1_i - e_j}{m_j}$$

$$e_j = y2_j - m_j\, x2_j$$

$$m_j = \frac{(y2_{j+1} - y2_j)}{(x2_{j+1} - x2_j)}$$

$i \leq j \leq N$ when $j+1 > N$, $\quad j+1 \Rightarrow 1$

$$HL_{min} = \min (HL2_i) \qquad i \ \forall\ 1, N$$

$$HL_{max} = \max (HL1_i)$$

The pitch is given by the difference of HL_{max} and HL_{min},

$$C = HL_{max} - HL_{min} \tag{3.9}$$

3.3 Calculation of Area Utilisation:

In case of single-row layout, the percentage area utilisation, u is given by the following expression,

$$u = \frac{A}{HC} \times 100 \tag{3.10}$$

The overall area utilisation is given by,

$$u_o = \frac{uMH}{S}, \tag{3.11}$$

where,

$$M = \frac{S}{H} - R \quad (R - \text{remainder of } S/H).$$

In case of pairwise layout, the area utilisation u is given by,

$$u = \frac{2A}{HC} \times 100 \tag{3.12}$$

The overall area utilisation is given by equation (3.11).

CHAPTER IV

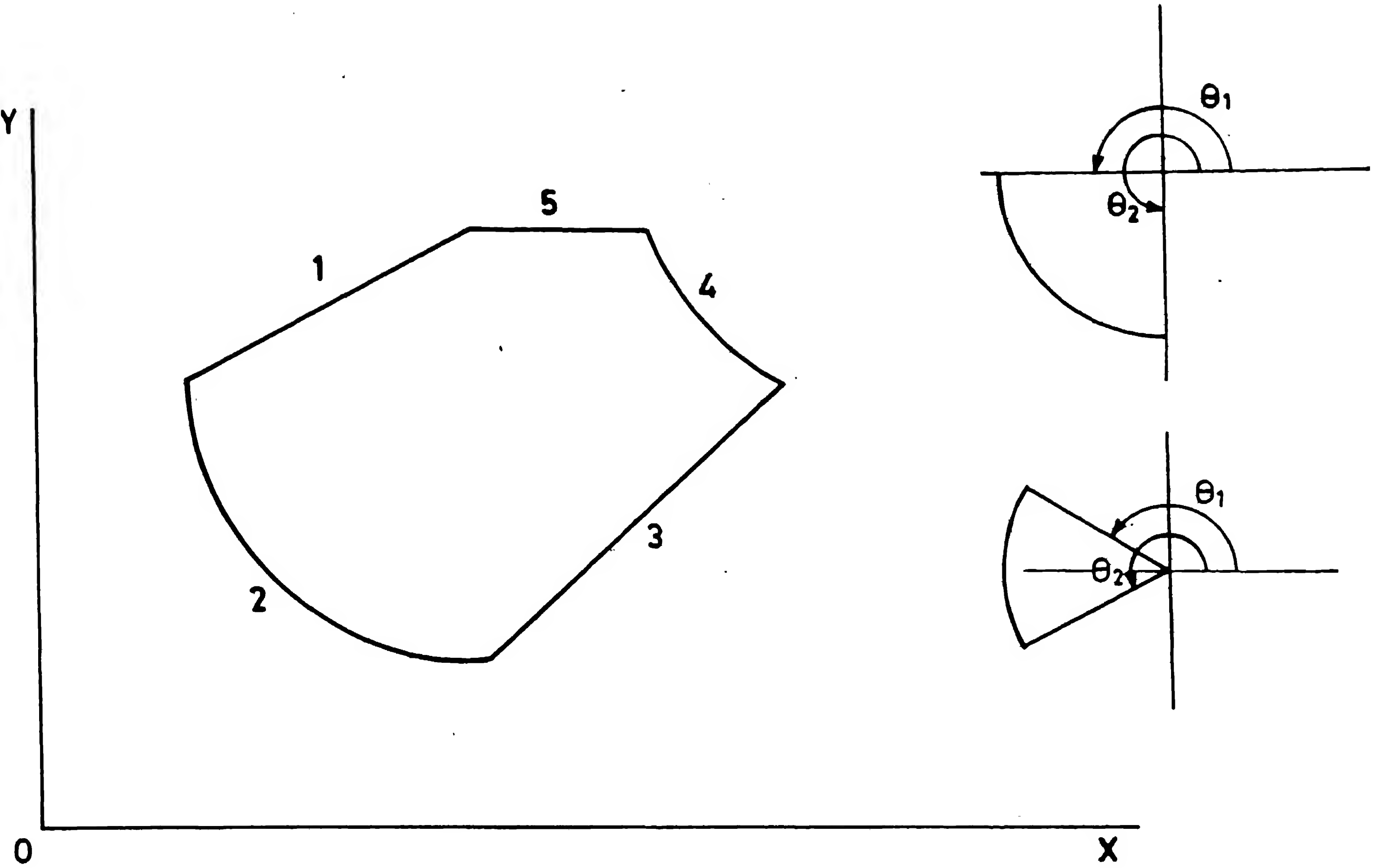
ALGORITHMS FOR LAYOUT OF A COMPONENT WITH CIRCULAR ARCS

Sheet metal components usually have circular arcs as part of their contours. One way of handling such a component is to approximate it to a polygon and its layout is obtained by procedures described in Chapter III. An alternative way is to represent the component as a series of segments (straight line or circular arc) and obtain the layout using their geometrical properties. In this chapter, the algorithms involved in the latter approach are described. The representation of component and its area calculation are described in Section 4.1. Section 4.2 gives the width and pitch calculation. The procedure for calculation of area utilisation and over all area utilisation remains the same as given in Section 3.3.

4.1 Component Representation and Area Calculation:

4.11 Component Representation:

The component is represented by its contour which is divided into segments that are numbered in the counter clockwise direction, as shown in Fig. 9. Each segment is either a straight-line segment or a circular arc segment. The



	S_{i_1} X_1	S_{i_2} Y_1	S_{i_3} X_2	S_{i_4} Y_2	S_{i_5} X_3	S_{i_6} Y_3	S_{i_7} IC
SEGMENT 1	30	40	10	30	-	-	2
SEGMENT 2	10	30	30	10	30	30	1
SEGMENT 3	30	10	50	30	-	-	2
SEGMENT 4	50	30	40	40	60	47.5	0
SEGMENT 5	40	40	30	40	-	-	2

CODE 2 STRAIGHT LINE
1 COUNTER CLOCKWISE ARC
0 CLOCKWISE ARC

FIG. 9 REPRESENTATION OF COMPONENT HAVING CIRCULAR ARCS ON IT'S CONTOUR.

circular arc segment can be either clockwise or anti-clock wise. As such there are three types of segments and they are identified by a code I_c as follows:

(i) Straight line segment, $I_c = 2$

(ii) Counter clockwise arc segment, $I_c = 1$

(iii) Clockwise arc segment, $I_c = 0$.

A segment is represented by the coordinates of its end points and the centre of the arc (in case of arc segment) and the code I_c. A component with N segments on its contour is represented as follows:

$$S_{ij} \qquad i \forall 1,N \text{ and } j \forall 1,7 \tag{4.1}$$

where,

$$\begin{aligned} S_{i1} &= (x^1)_i \\ S_{i2} &= (y^1)_i \\ S_{i3} &= (x^2)_i \\ S_{i4} &= (y^2)_i \qquad\qquad i \forall 1, N \\ S_{i5} &= (x^c)_i \\ S_{i6} &= (y^c)_i \\ S_{i7} &= (I_c)_i \end{aligned}$$

The component in any other orientation ϕ is represented as follows:

$$S'_{ij} \qquad i \forall 1,N \text{ and } j \forall 1, 7 \tag{4.2}$$

where,

$$\begin{array}{llll} \text{for } j = 1,3,5 & S'_{ij} = S_{ij}\cos\phi - S_{ij+1}\sin\phi & & \\ \text{for } j = 2,4,6 & S'_{ij} = S_{ij}\cos\phi + S_{i,j-1}\,\text{Sin}\,\phi & & i \,\forall\, 1,N \\ \text{for } j = 7 & S'_{ij} = S_{ij} & & \end{array}$$

The start angle θ_1 and end angle θ_2 representing the span of the arc segment are illustrated in Fig. 10. Angles θ_1 and θ_2 are so defined that θ_1 is always greater than θ_2 for counter clockwise arcs and θ_2 is always greater than θ_1 for clockwise arcs.

To calculate θ_1 and θ_2, the shortest angle made by the start and end lines with the positive x-axis in the counter clockwise direction θ_1 and θ_2 are determined as follows:

When $I_c = 1$ or 0

$$(\theta'_1)_i = \tan^{-1}\left[\left(\frac{(y^1 - y^c)}{(x^1 - x^c)}\right)_i\right]$$

$$(\theta'_2)_i = \tan^{-1}\left[\left(\frac{(y^2 - y^c)}{(x^2 - x^c)}\right)_i\right] \qquad i \,\forall\, 1,N \qquad (4.3)$$

The angles θ_1 and θ_2 are calculated by the following expressions. For clockwise arc segments,

i.e. when $I_c = 0$

$$\text{if} \quad (\theta'_2)_i > (\theta'_1)_i$$

$$(\theta'_1)_i = (\theta'_1)_i + 360^\circ \qquad i \,\forall\, 1,N \qquad (4.4a)$$

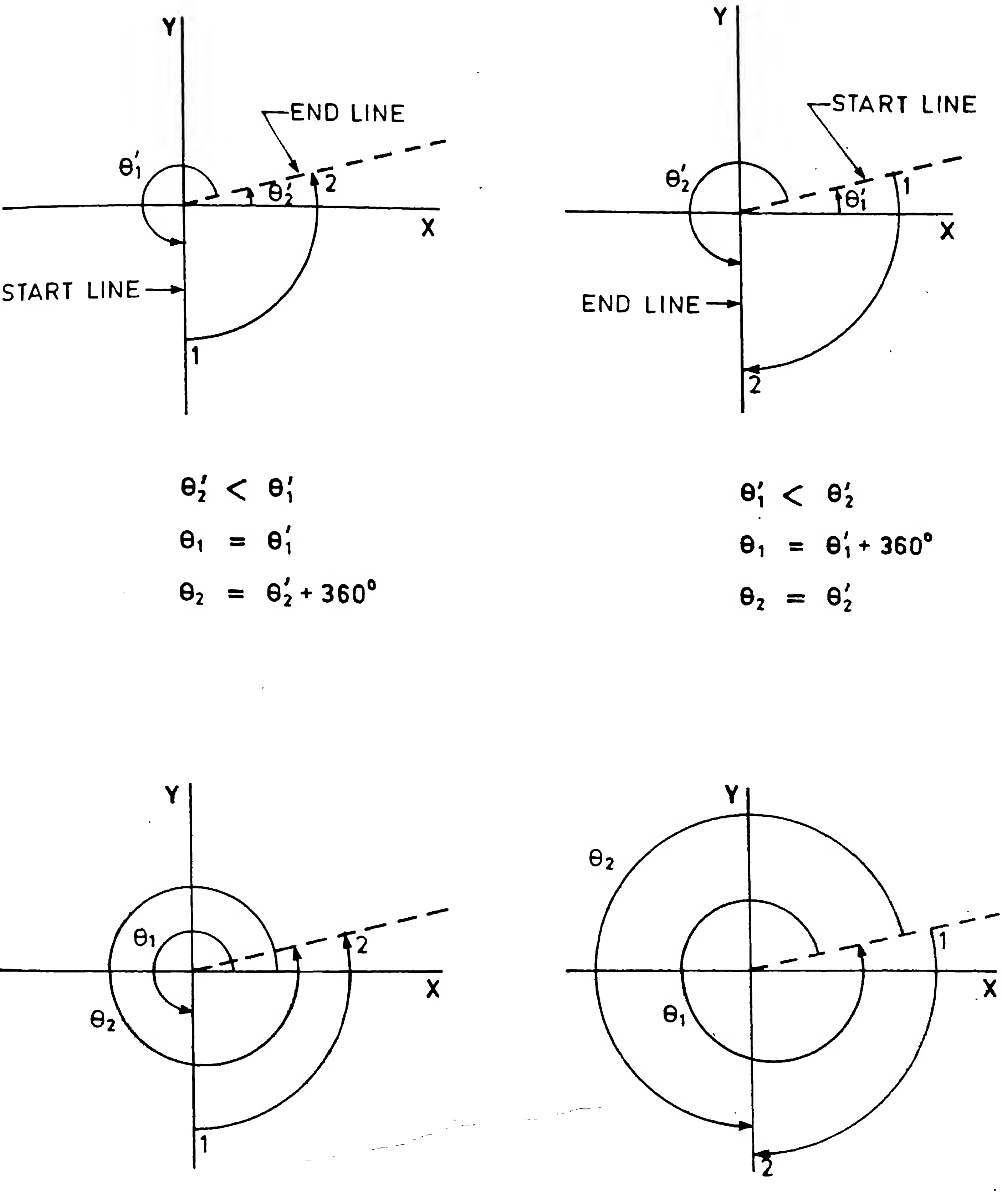


FIG. 10 ILLUSTRATION OF ANGLES θ_1', θ_2', θ_1 AND θ_2

For counter clockwise arc segments,

i.e. when $I_c = 1$

$$\text{IF } (\theta_2')_i < (\theta_1')_i \qquad i \ \forall\ 1,N \qquad (4.4b)$$
$$(\theta_2')_i = (\theta_2')_i + 360^\circ$$

otherwise for both clockwise and counter clockwise arc segments,

$$(\theta_1)_i = (\theta_1')_i \qquad i \ \forall\ 1,N \qquad (4.4c)$$
$$(\theta_2)_i = (\theta_2')_i$$

4.12 Area Calculation:

The area is calculated by dividing the component into several sub areas as shown in Fig. 11, about a central point $(\bar{x}, \bar{y})$.

Where,

$$\bar{x} = \sum_{i=1}^{N} \frac{x_i}{N} \qquad (4.5)$$
$$\bar{y} = \sum_{i=1}^{N} \frac{y_i}{N}$$

For the purpose of illustration the central point is chosen such that the different sub-areas to be added and subtracted are clearly demarcated.

The end points of all segments are joined to this central point $(\bar{x}, \bar{y})$ to divide the area into triangles and segment of a circle. The area included by the triangles is

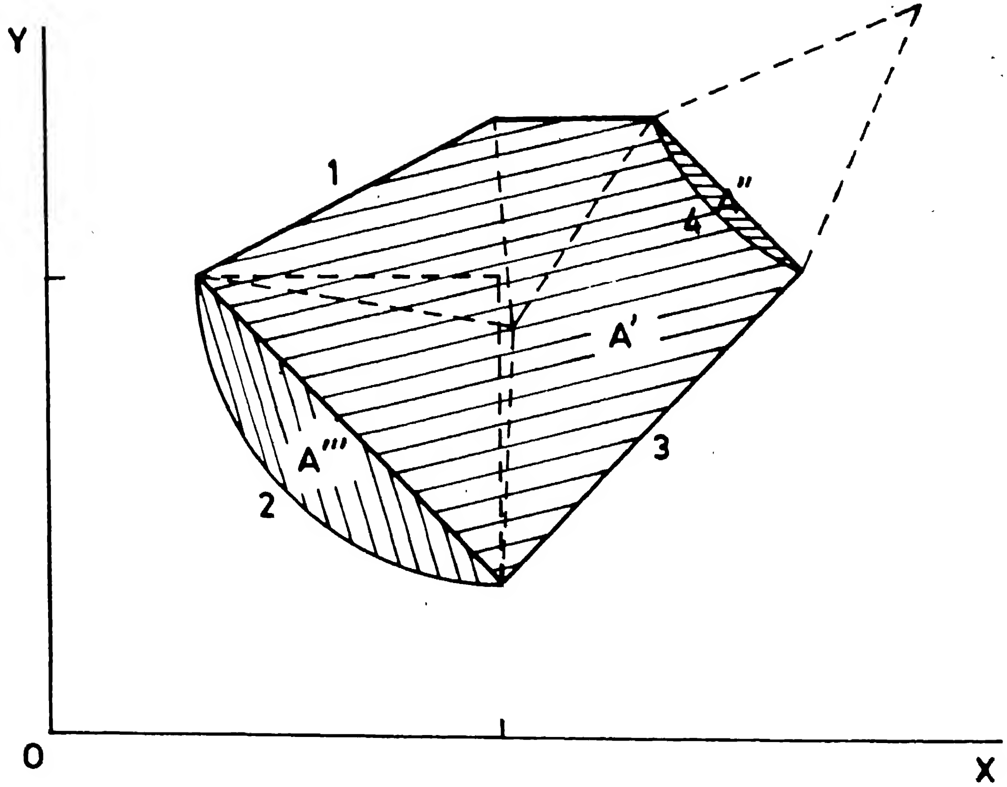


FIG. 11 ILLUSTRATION OF AREA CALCULATION.

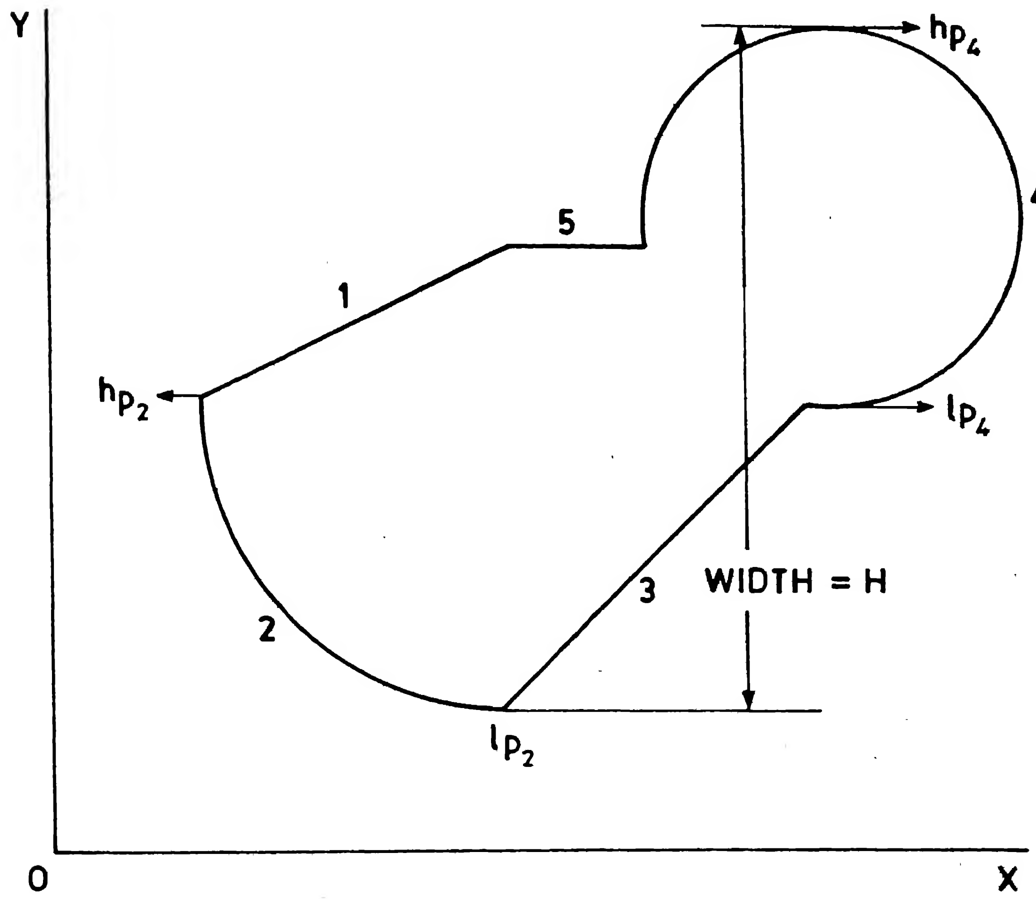


FIG. 12 ILLUSTRATION OF WIDTH CALCULATION.

given by,

$$A' = \sum_{i=1}^{N} \frac{1}{2} \left(\begin{vmatrix} 1 & 1 & 1 \\ x^1 & x^2 & \bar{x} \\ y^1 & y^2 & \bar{y} \end{vmatrix} \right)_i \qquad (4.6)$$

The area of the segments of clockwise arcs ($I_c = 0$) is given by,

$$A'' = \sum_{i=1}^{N} \left[-0.5(\theta_1-\theta_2)\, r^2 + \frac{1}{2} \begin{vmatrix} 1 & 1 & 1 \\ x^1 & x^2 & x^c \\ y^1 & y^2 & y^c \end{vmatrix} \right]_i \qquad (4.7)$$

where, $r = \sqrt{(x^c - x^1)^2 + (y^2 - y^1)^2}$

The area of the segments of count r clockwise arcs ($I_c = 1$) is given by,

$$A''' = \sum_{i=1}^{N} \left[0.5\, (\theta_1-\theta_2)\, r^2 - \frac{1}{2} \begin{vmatrix} 1 & 1 & 1 \\ x^1 & x^2 & x^c \\ y^1 & y^2 & y^c \end{vmatrix} \right]_i \qquad (4.8)$$

The total area of the component A is given by,

$$A = A' + A'' + A''' \qquad (4.9)$$

4.2 Width and Pitch Calculations

4.21 Width Calculation:

The width H is the difference between the maximum of y-coordinates of highest points $(hp)_i$ and minimum of y-coordinates of lowest points $(lp)_i$ of all segments:

$$H = \max (y_i^{hp}) - \min (y_i^{lp}) \qquad (4.10)$$

The highest point hp_i and lowest point lp_i of all segments is determined in the following way.

For the straight line segment the highest and lowest points correspond to the higher and lower of the y-coordinates of the end points, respectively. For circular arc segments the points hp_i and lp_i may or may not coincide with the end points (Fig. 12). In that case the points hp_i and lp_i are determined as follows.

IF $(I_c)_i = 1$ and $(\theta_1)_i \leq 90^\circ \leq (\theta_2)_i$

or $(I_c)_i = 0$ and $(\theta_2)_i \leq 90^\circ \leq (\theta_1)_i$

then,

$$x_i^{hp} = (x^c)_i \qquad\qquad i \,\forall\, 1,N$$

$$y_i^{hp} = (y^c + r)_i$$

IF $(I_c)_i = 1$ and $\theta_1 \leq 270^\circ \leq \theta_2$

or $(I_c)_i = 0$ and $\theta_2 \leq 270^\circ \leq \theta_1$

then, $\qquad\qquad i \,\forall\, 1,N \qquad (4.1$

$$x_i^{lp} = (x^c)_i$$

$$y_i^{lp} = (y^c)_i - r_i$$

otherwise,

$$y_i^{lp} = \min\,(y_i^1,\ y_i^2)$$

$$y_i^{hp} = \max\,(y_i^1,\ y_i^2)$$

4.22 Pitch Calculation:

The terminology used in the determination of pitch is described below (Fig. 13).

Horizontal Length hl_i of a segment is the longest of Horizontal Distances $hd_{i,j}$ between the i-th segment and all other j-th segments with which it has a Common y-Range .

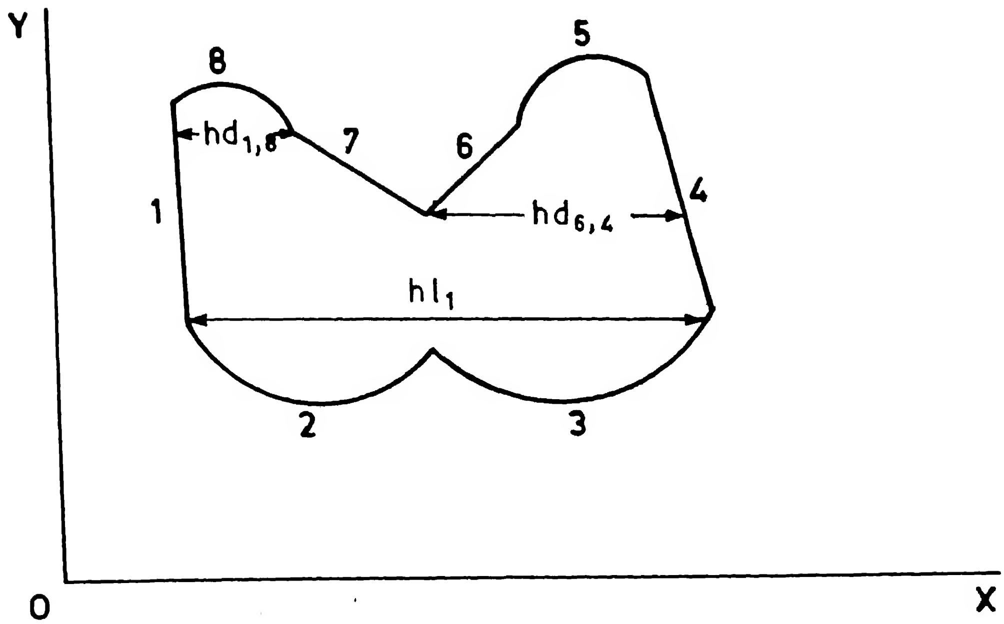
Horizontal Distance $hd_{i,j}$ between two segments which have a Common y-Range is the longest horizontal distance between the two segments.

Common y-Range between two segments i and j is the range of y-values which are common to both the segments. The Common y-Range is defined by the upper boundary and lower boundary. The upper boundary coincides with the second highest point B1 of the points hp_i, hp_j, lp_i, lp_j and the lower boundary coincides with the second lowest point B2.

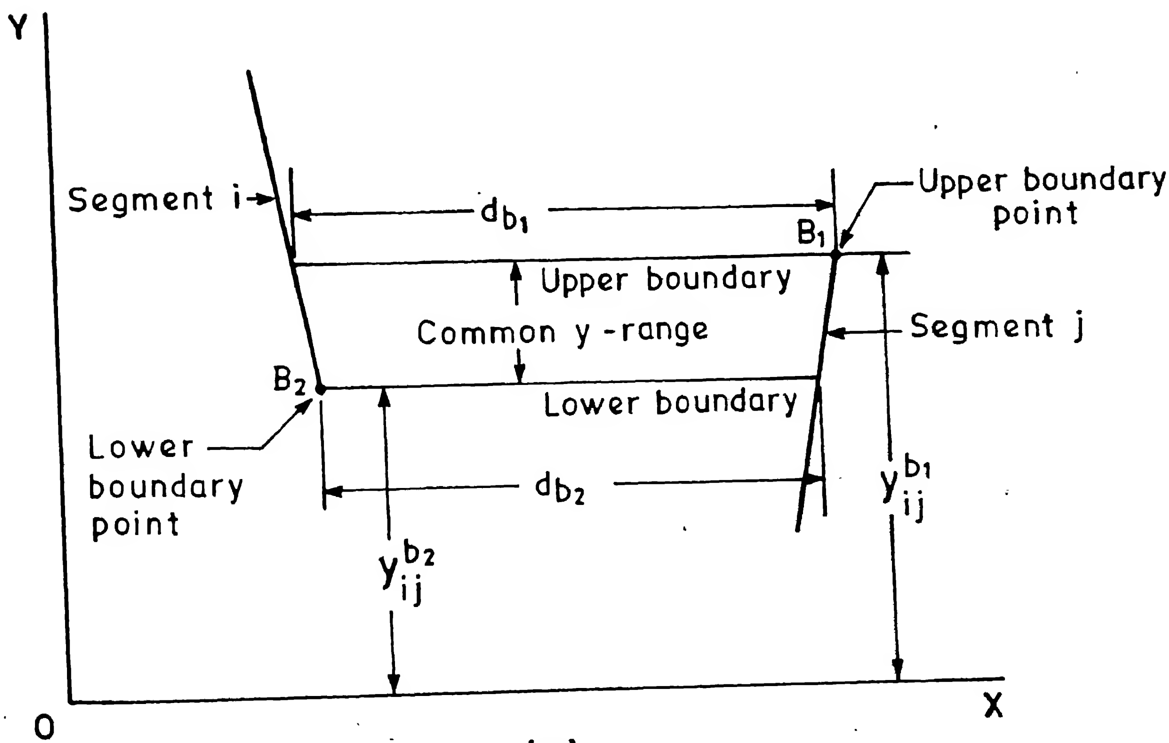
The determination of Horizontal Distance hd_{ij} for different types of segments i and j is carried out in the following manner.

(i) If i and j are straight line segments, the horizontal distance between i and j at the boundary points of the Common y-Range are determined (Fig. 13).

$$hd_{i,j} = \max (db_1, db_2)$$



(a)



(b)

FIG. 13 ILLUSTRATION OF TERMINOLOGY FOR CALCULATION OF PITCH.

where,

$$db_1 = | x^{b_1} - x_{incpt} |$$
$$db_2 = | x^{b_2} - x_{incpt} | \qquad (4.12)$$

where, B_1 and B_2 are the boundary points.

$$x_{incpt} = \frac{y_{b_k} - e_l}{m_i} \qquad k = 1 \text{ or } 2 \text{ and } l = i \text{ or } j.$$

(ii) Segments i and j are a straight line and an arc:
The variation of horizontal distance between a straight line and a circle is shown in the Fig. 14. It is seen that there is only one maximum, and on either side of the maximum. The horizontal distance decreases. There is also a minimum, on either of which the horizontal distance increases. The maximum and minimum horizontal distance, d_{max} and d_{min}, occur at y-values given by,

$$y_{max} = y_j^c \pm \frac{r_j}{\sqrt{1 + 4m_i^2}} \qquad (4.13)$$

The arc segment can be any part of the circle shown in Fig.14. If y_{max} happens to be in the Common y-range then,

$$(hd)_{ij} = \max |x_i^{incpt} - x_j^{incpt}| \qquad (4.14)$$

where,

$$x_i^{incpt} = \frac{y_{max} - e_i}{m_i}$$

$$x_j^{incpt} = x_j^c \pm (r_j^2 - (y_{max} - y_j^c)^{1/2}$$

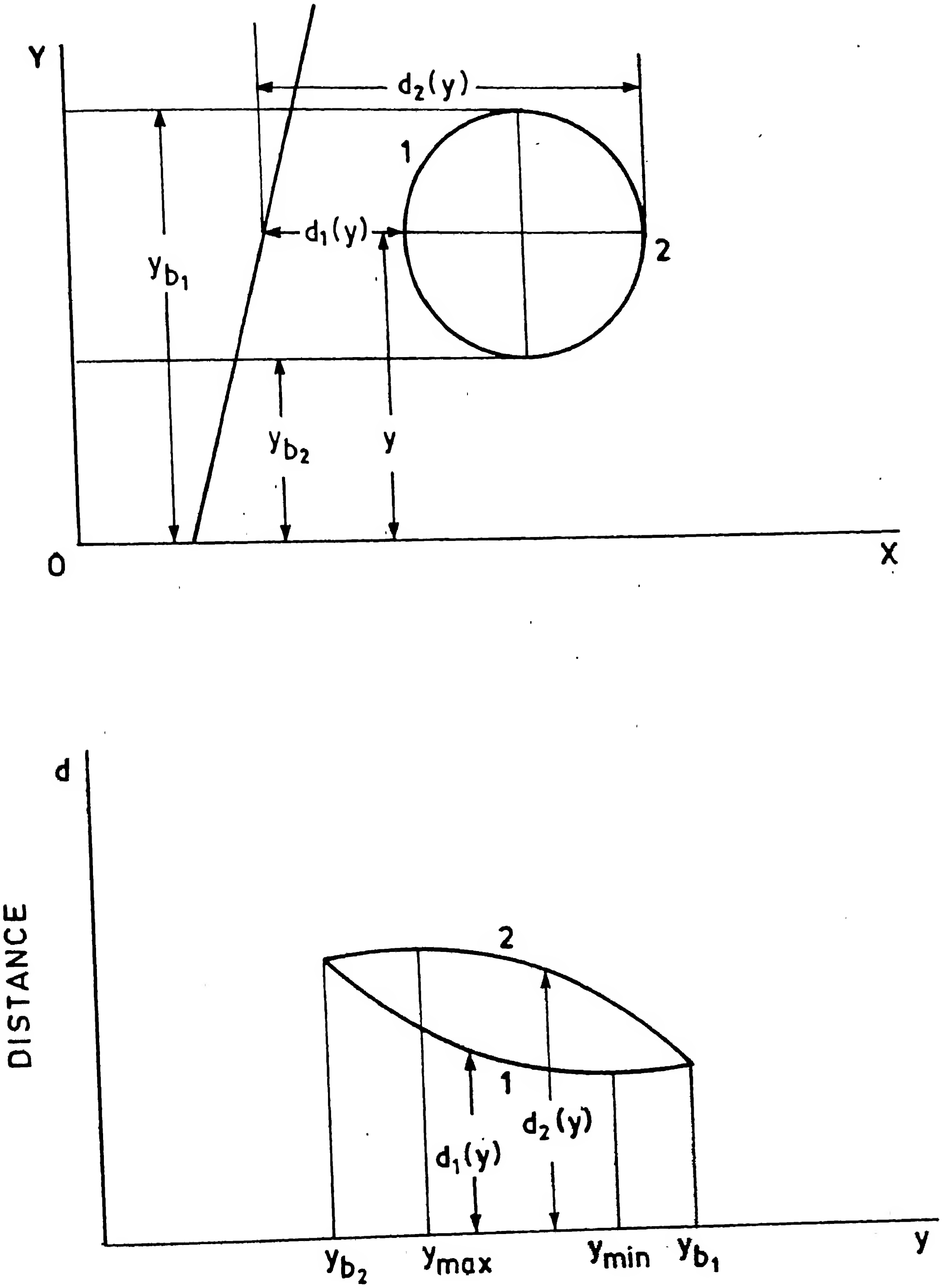


FIG. 14 VARIATION OF DISTANCE BETWEEN A CIRCLE AND A STRAIGHT LINE.

The above expression gives two values of x-coordinates for two inter-section points of the circle. Whether one or both of the inter-section points is actually on the arc is checked by calculating the angle θ_j^{incpt} for inter-section points and checking whether this angle is in the θ limits of the arc, θ_1 and θ_2.

If y_{max} is not in the Common y-Range, then the longest horizontal distance lies at one of the boundaries of the Common y-Range. Using equations 4.12 and 4.14 the horizontal distances of the boundary points d_{b_1} and d_{b_2} are determined and $hd_{i,j}$ is given by,

$$hd_{i,j} = \max (d_{b_1}, d_{b_2}) \tag{4.15}$$

(iii) Segments i and j are both circular arcs:

The variation of horizontal distance between two circles of radii r_i, r_j and center at (x_i^c, y_i^c), (x_j^c, y_j^c), as a function of y are given by,

$$d_{ij}(y) = x_i^c - x_j^c \pm \sqrt{r_i^2 - (y - y_i^c)^2} \mp \sqrt{r_j^2 - (y - y_j^c)^2} \tag{4.16}$$

The variation of d_{ij} is plotted against Common y-Range in Fig. 15. The following three cases are illustrated.

(i) The center of the two circles have different y-coordinates but the smaller circle is partially in the y-limits of the bigger circle. Fig. 15(a).

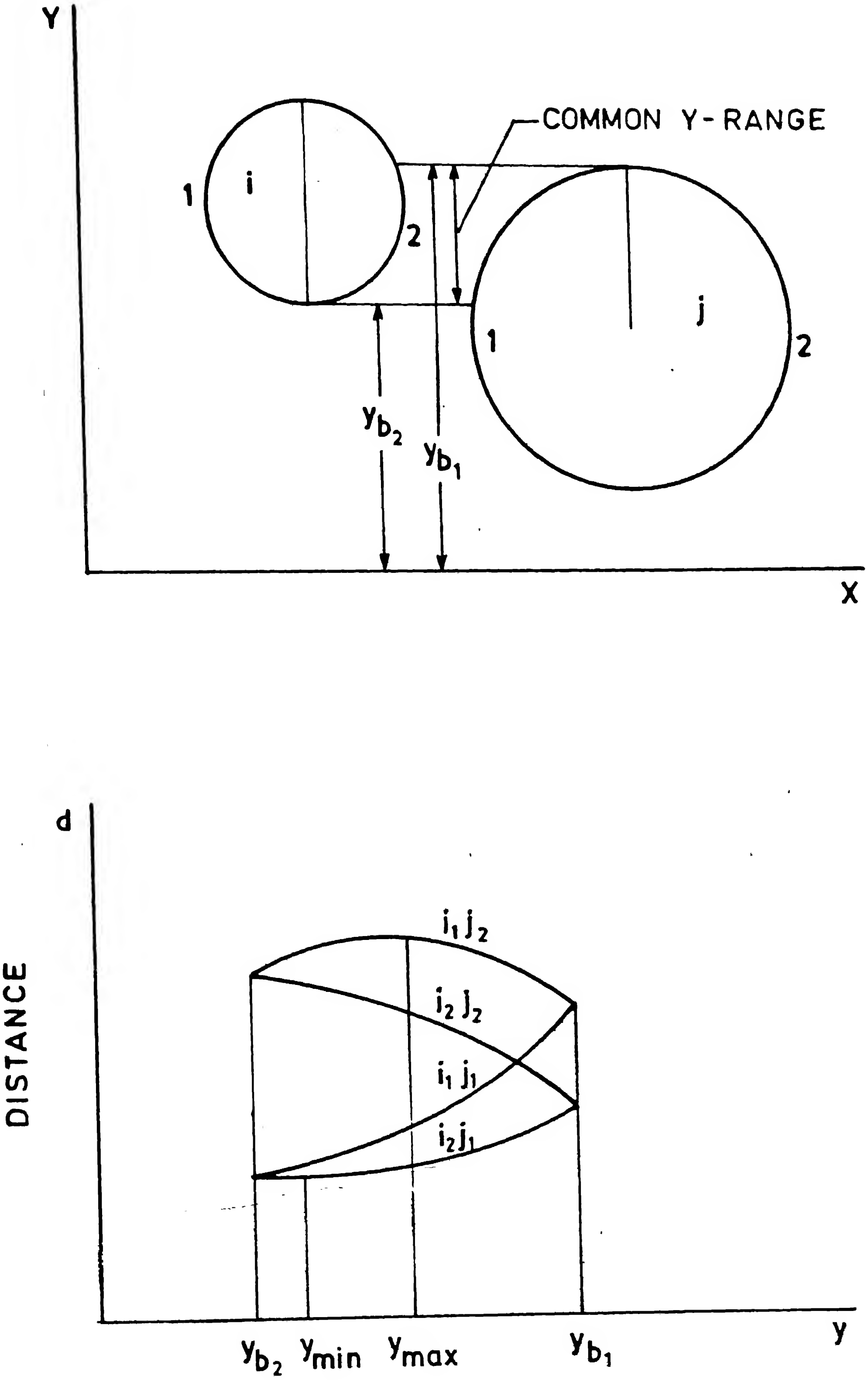


FIG. 15 a. VARIATION OF DISTANCE BETWEEN TWO CIRCLES.

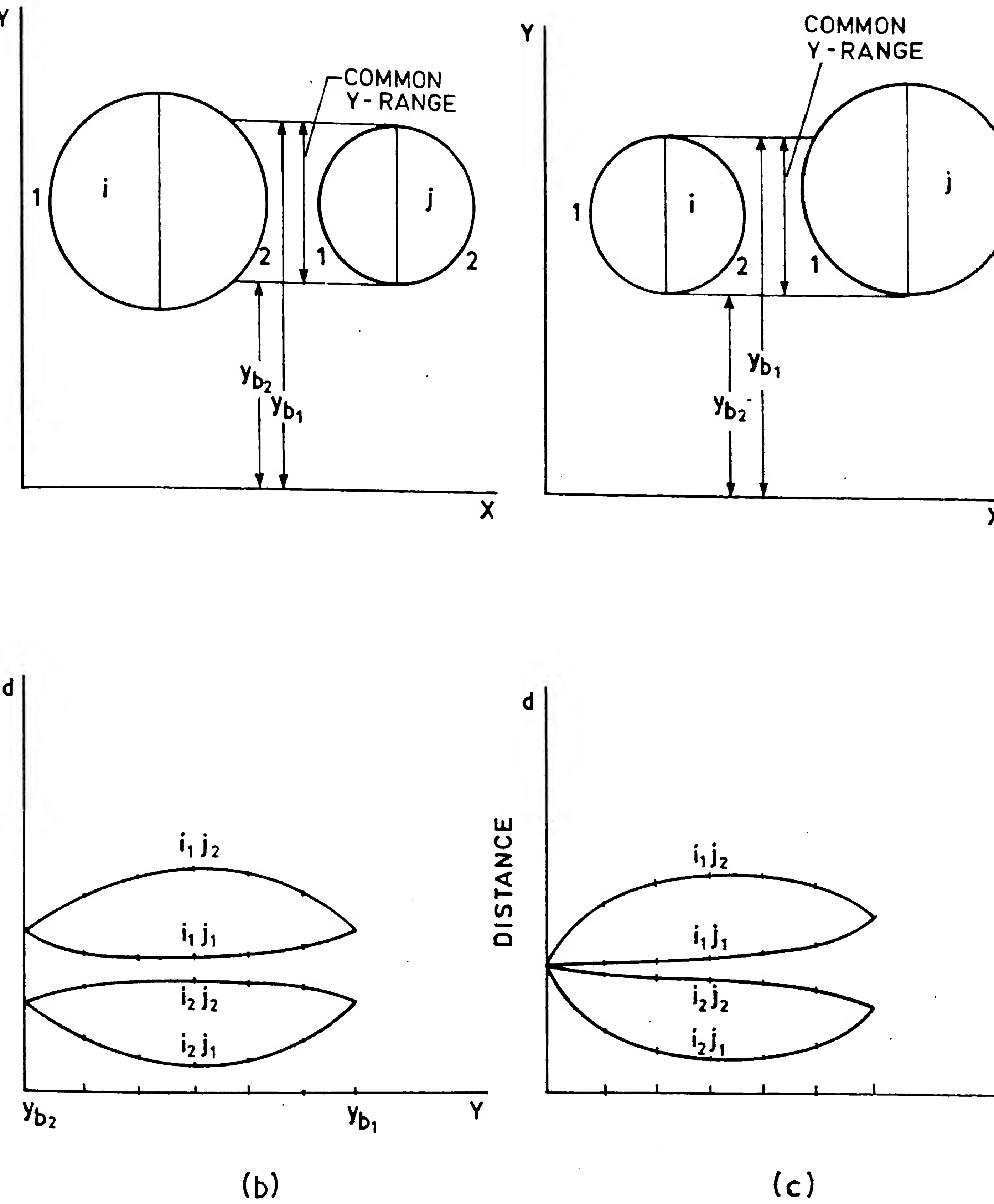


FIG. 15 (b) & (c) VARIATION OF DISTANCE BETWEEN TWO CIRCLE

(ii) The center of two circles have same y-coordinates. Fig.15(b).

(iii) The center of two circles have different y-coordinates and the smaller circle is fully in the y-limits of the bigger circle Fig. 15(c).

It is observed that the maximum and minimum y-values occur at the same y-value and is given by,

$$y_{max} = \frac{r_i\, y_j^c - r_j\, y_i^c}{r_i - r_j} \quad \text{when } r_i \neq r_j$$

when $r_i = r_j$ (4.17)

$$y_{max} = \frac{y_j^c + y_i^c}{2}$$

If y_{max} happens to be in the Common y-Range then $d_{i,j}^{max}$ is given by,

$$d_{i,j}^{max} = \max\left(|x_i^{incpt} - x_j^{incpt}|\right) \qquad (4.18)$$

where,

$$x_i^{incpt} = x_i^c \pm \sqrt{r_i^2 - (y_{max} - y_i^c)^2}$$

$$x_j^{incpt} = x_j^c \pm \sqrt{r_j^2 - (y_{max} - y_j^c)^2}$$

The points (x_i^{incpt}, t_{max}) and (y_j^{incpt}, y_{max}) are checked as to, whether they lie on the respective arcs by the method described in case (ii), before using these values in Eq. (4.18).

The distances d_{i_j} are calculated at boundary y-values also by using expression (4.18). The Horizontal Distance $hd_{i,j}$ is given by,

$$(hd)_{i,j} = \max \left(d_{i,j}^{max},\ d_{i,j}^{b_1},\ d_{i,j}^{b_2}\right) \qquad (4.19)$$

The Horizontal Length hl_i of a segment is the maximum of Horizontal Distance $hd_{i,j}$ and is given by,

$$hl_i = \max (hd_{i,j}) \quad j \forall \; i, N \qquad (4.20)$$

The pitch is calculated by taking the maximum of Horizontal Lengths hl_i of all segments.

$$C = \max (hl_i) \quad i \forall \; 1, N \qquad (4.21)$$

The algorithm presented for pitch calculation is only for single row layout. But it can be extended to double row layouts also, by following the approach described in Chapter III for the case of pairwise layout of polygon shaped component.

CHAPTER V

ALGORITHMS FOR BLANKING DIE DESIGN

The algorithms involved in the design of a simple blanking die are elaborated in this chapter. The design procedure described in Section 2.4 of Chapter II is followed. The calculation of perimeter and center of pressure of the component, and the blanking force are described in Sec. 5.1. The die and punch calculations are described in Sec. 5.2. Section 5.3 gives the algorithms for getting sectional views of the die assembly. The design procedure is implemented only for the case of the component that can be represented as a polygon.

5.1 Blanking Force Calculation:

The perimeter P of the blank is given by the following expression.

$$P = \sum_{i=1}^{N} [(x_i^2 - x_i^1)^2 + (y_i^2 - y_i^1)^2]^{\frac{1}{2}} i \;\forall\; 1, N \qquad (5.1)$$

The coordinates of the center of pressure $(\bar{X}, \bar{Y})$ are calculated by the following expressions,

$$\bar{X} = \sum_{i=1}^{N} \frac{\sqrt{\left((x_i^2 - x_i^1)^2 + (y_i^2 - y_i^1)^2 \right)}\,(x_i^1 + x_i^2)}{2P}$$

$$\bar{Y} = \sum_{i=1}^{N} \frac{\sqrt{\left((x_i^2 - x_i^1) + (y_i^2 - y_i^1)^2 \right)}\,(y_i^1 + y_i^2)}{2\,P} \qquad (5.2)$$

Blanking force is given by,

$$F = P \times t \times u_s \quad \text{Newtons} \qquad (5.3)$$

where, t = sheet thickness in mm

u_s == ultimate shear strength of the material in N/mm^2

The press of required tonnage is selected.

5.2 Die and Punch Calculations:

The die thickness t_d is calculated either by Method I or by Method II. The die area required is calculated in the following manner. The maximum x and y coordinates of the component are determined as x_m, y_m,

$$\begin{aligned} x_m &= \max(x_i) \\ y_m &= \max(y_i) \end{aligned} \qquad i \;\forall\; 1, N \qquad (5.4)$$

Method I: The length of l_d and width w_d of the die required is

$$\begin{aligned} w_d &= 2 \max(\bar{Y}, (y_{max} - \bar{Y})) + 64 \\ l_d &= 2 \max(\bar{X}, (y_{max} - \bar{Y})) + 64 \end{aligned} \qquad (5.5a)$$

Method II: l_d and w_d are given by,

$$w_d = 2 \max (\bar{Y}, (y_{max} - \bar{Y})) + 1.5\, t_d$$
$$l_d = 2 \max (\bar{X}, (y_{max} - \bar{Y})) + 1.5\, t_d \quad (5.5b)$$

Once l_d and w_d are calculated, the die set is selected.

The punch for blanking will have a clearance C_p and its coordinates are calculated in the following manner. Figure 16 shows the clearance C_p applied to the punch for a polygon shaped component. The calculation of the punch coordinates involves determining the equations of its sides, and then solving them to get the required coordinates i.e. if the equation of the side of a component is given by,

$$y = mx + e \quad (5.6)$$

The equation of parallel line to it is obtained by adding to or subtracting from x-intercept or y-intercept, as illustrated in Fig. 17. For all inclined lines the equation of the required parallel line is given by the following expression,

$$y = mx + e \pm C_p \sqrt{1 + m^2} \quad (5.7)$$

For horizontal lines the required equation of the parallel line is obtained by adding or subtracting C_p from the y-intercept e.

$$y = e \pm C_p \quad (5.8)$$

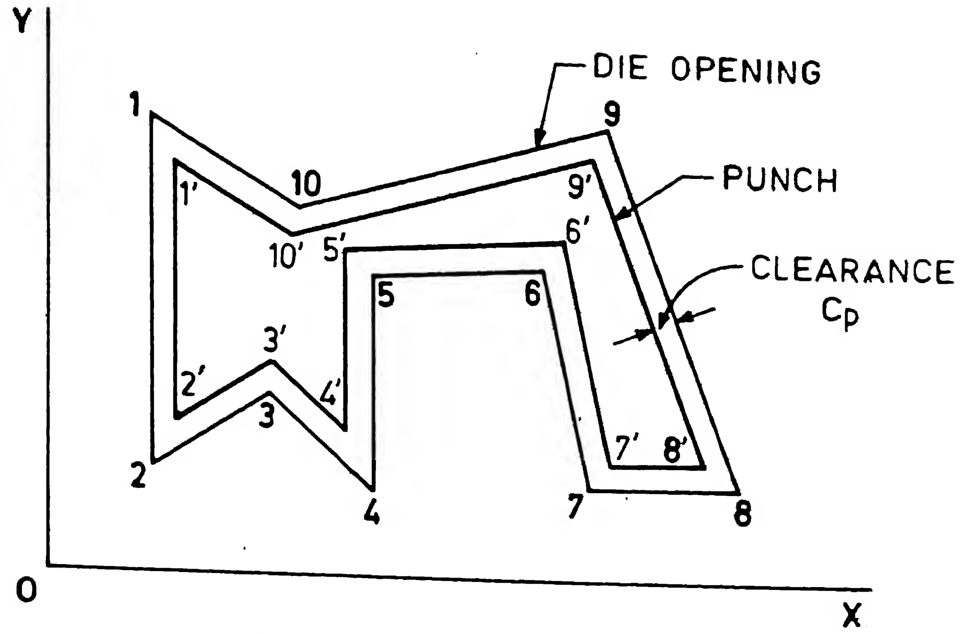


FIG. 16. ILLUSTRATION OF PUNCH CLEARANCE APPLICATIO

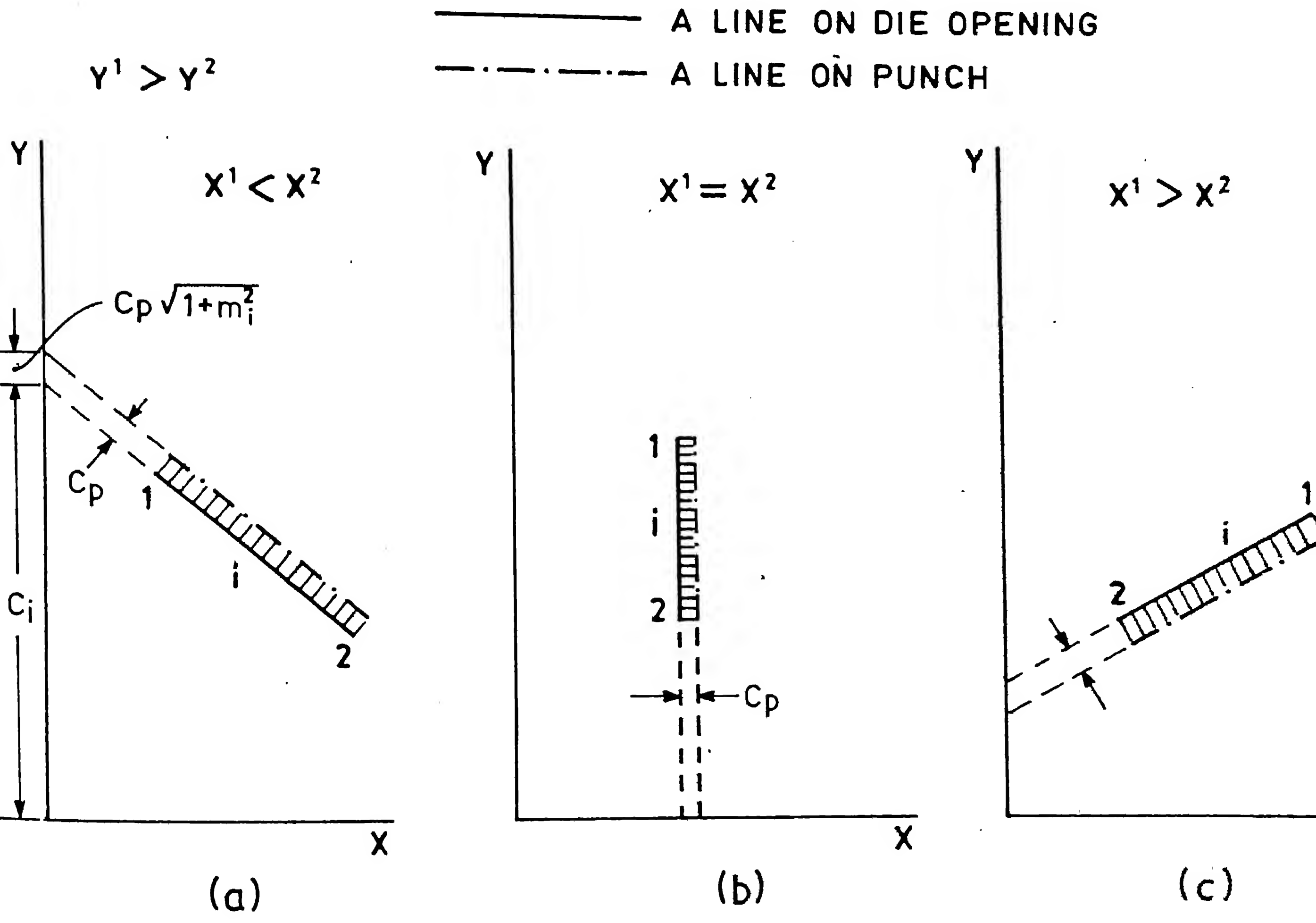


FIG. 17 (contd.)

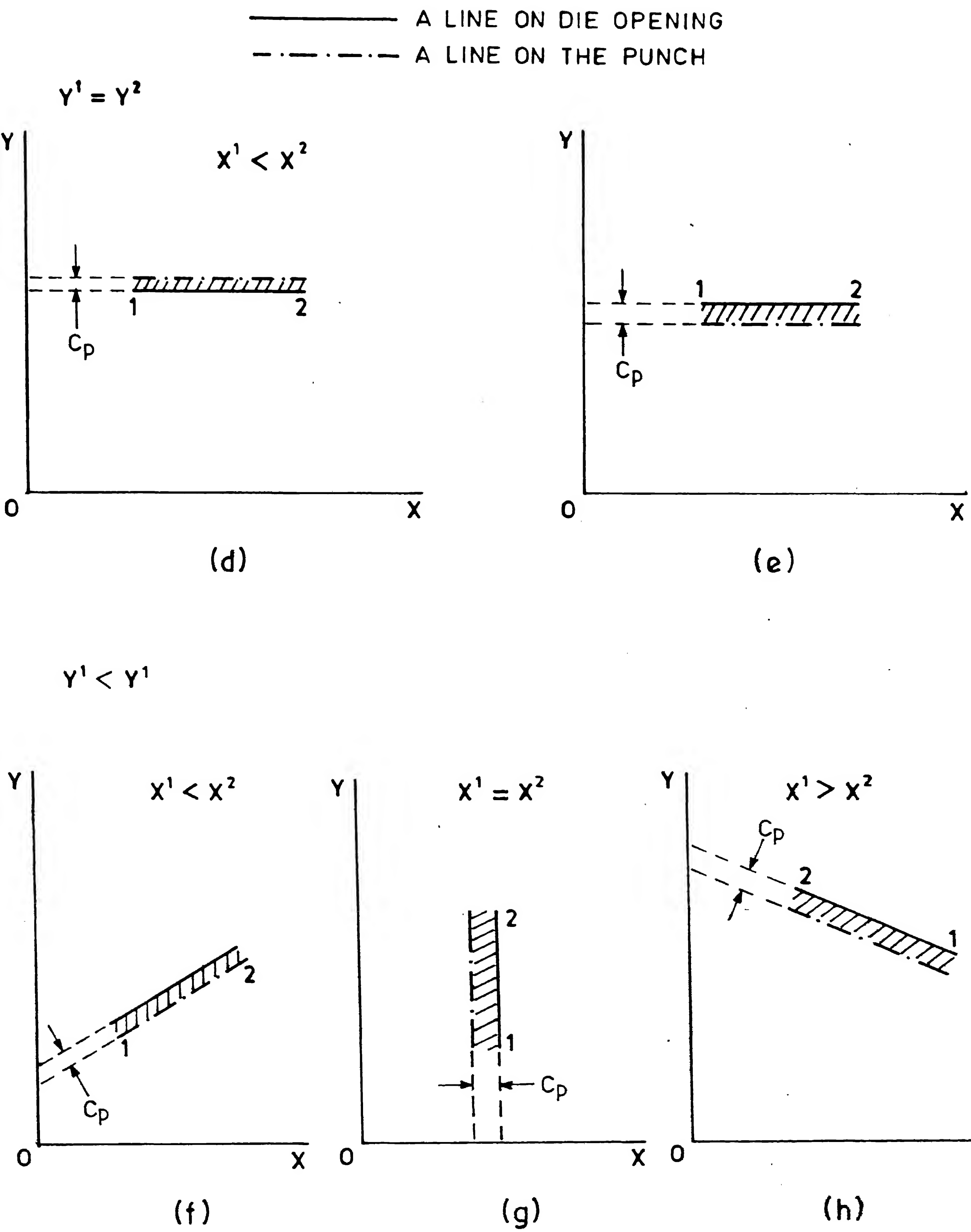


FIG. 17 ILLUSTRATION OF PUNCH COORDINATE CALCULATION.

For vertical lines the equation of the required parallel line is given by the following expression.

$$x = f \pm C_p \tag{5.9}$$

where f is the x-intercept of the line. The equations of two adjacent sides are solved simultaneously to get the coordinates of their inter-section point.

5.3 Sectional Views of the Die Assembly:

The die assembly drawings constitute of a plan, sectional elevation and a sectional side view. Since the component is of a general shape the points of inter-section are determined for getting sectional views of the die assembly. The intersection points for sectional elevation are calculated by the following expressions.

$$\left.\begin{array}{ll} \text{For} & y_i \leq y_{ip} \leq y_{i+1} \\ \text{or} & y_{i+1} \leq y_{ip} \leq y_i \end{array}\right\} \quad i \;\forall\; 1,N \tag{5.10}$$

$$x_{ip}(I) = \frac{y_{ip} - e_i}{m_i} \qquad I \;\forall\; 1, I_e$$

where I_e = number of inter-section points for elevation

$$e_i = y_i - m_i x_i$$

$$m_i = \frac{y_{i+1} - y_i}{x_{i+1} - x_i}$$

where y_{ip} is the chosen inter-section coordinate.
Similarly the inter-section points for sectional side view are calculated by the following expressions.

$$\left.\begin{array}{ll} \text{For} & x_i \leq x_{ip} \leq x_{i+1} \\ \text{or} & x_{i+1} \leq x_{ip} \leq x_i \end{array}\right\} \quad i \;\forall\; 1, N \tag{5.11}$$

$$y(I) = m_i \, x_{ip} + e_i \qquad I \;\forall\; 1, I_s$$

where I_s = number of inter-section points for sectional side-view.

where,

$$e_i = y_i - m_i x_i$$

$$m_i = \frac{y_{i+1} - y_i}{x_{i+1} - x_i}$$

x_{ip} = chosen inter-section coordinate.

CHAPTER VI

IMPLEMENTATION OF LAYOUT AND DIE DESIGN ALGORITHMS

In this chapter the implementation of algorithms developed in Chapters III to V as a package is described. The layout and die design of polygon shaped components is built in to a single program (hereafter referred to as Program I). The layout design of components with circular arcs on their contours is developed as a separate program. (hereafter referred to as Program II). The programs are developed using Fortran 77 language with PLOT-10 IGL graphics package on OMEGA-58000 system. The graphical representation of sectional views of the die assembly, text representation are involved in Program I and hence PLOT-10 IGL which is a very powerful graphics package is most appropriate for developing the above program. The PLOT 10-IGL graphics routines can be called only from a Fortran 77 Program [11].

The organisation of both the programs is described with flow charts in Section 6.1. The use of the program to test the algorithms for a typical example is described in Section 6.2.

6.1 Organisation of Programs:

The flow chart of Program I is shown in Fig. 18. The entire program with its sub-routines is stored in one source file. The data on die set, press, and die design tables are stored in a input file and are read at the start of the program. The output data regarding the layout coordinates, pitch, area utilisation and dimensions of die, die set and punch is stored in a output file. The graphical outputs of the program namely the layout and sectional views of die assembly can be stored into a file or can be plotted on a plotter.

The different sub-routines involved with Program I are described briefly below.

Subroutine WIDTH:

The current y-coordinates and number of vertices are passed into this sub-routine and it returns the width.

Subroutine PITCH:

The current x and y coordinates are passed and it returns the pitch for single row layout.

Subroutine MAXMIN:

The current x and y values of the component are passed and it returns maximum and minimum of x and y values for pairwise layout.

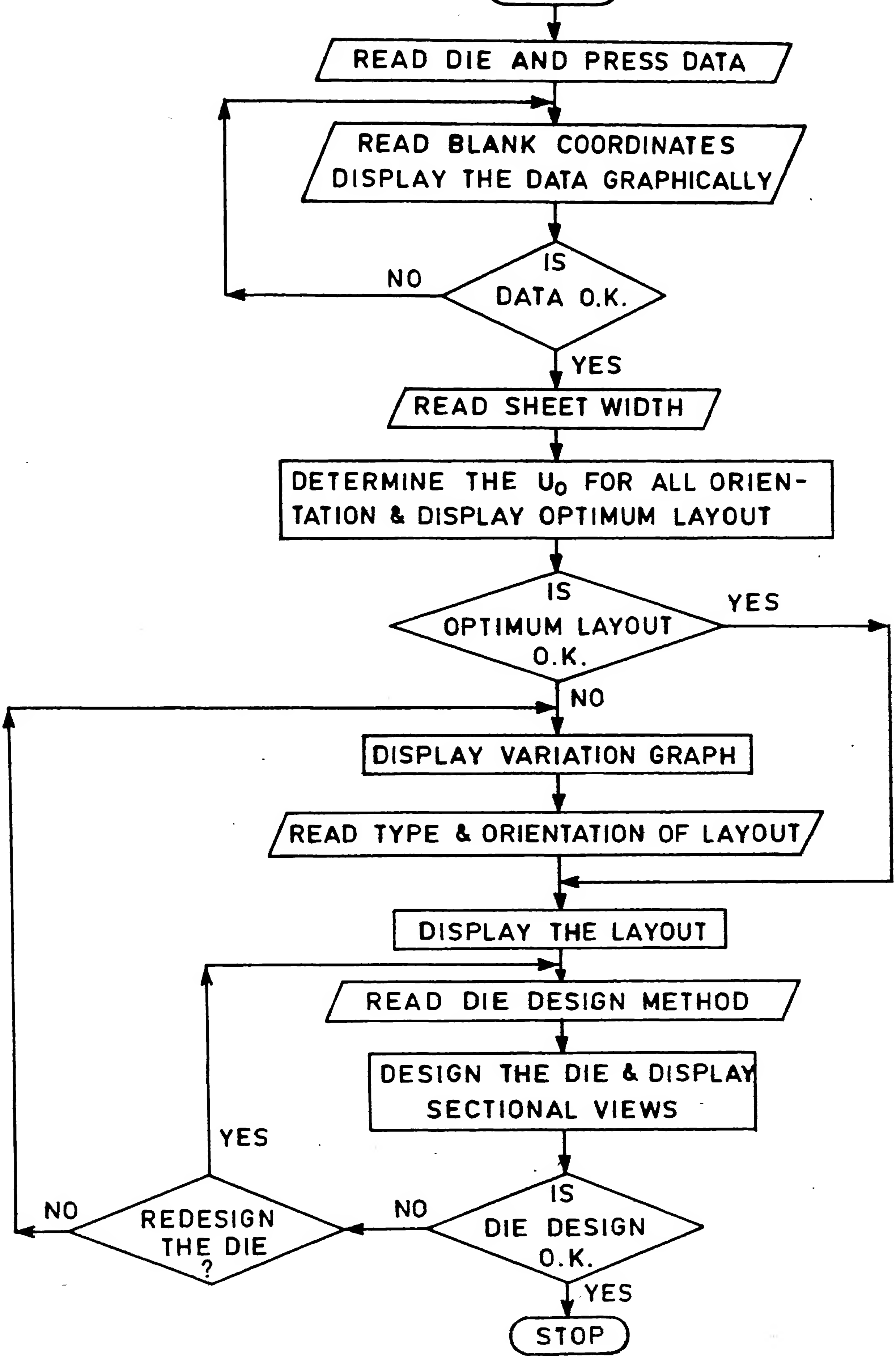


FIG. 18 FLOWCHART OF PROGRAM 1

Subroutine DPITCH:

The current x and y coordinates of the component and its pair are passed and it returns the pitch for double row layout.

Subroutine PERIPR:

The x and y coordinates of the component in selected layout are passed and it returns the perimeter and coordinates of center of pressure.

Subroutine PUNCO:

The x and y coordinates of the component in the selected layout and required punch clearance are passed and it returns the punch coordinates.

Subroutine XVAL:

The selected x and y coordinates of the component and intersecting y-coordinate are passed and it returns the x-coordinates of inter-section points.

Subroutine YVAL:

The selected x and y coordinates of the component and intersecting x-coordinate are passed and it returns the y-coordinates of inter-section points.

Subroutine XINCPT:

An inter-secting y-coordinate and x and y coordinates of a chosen line are passed and it returns the x coordinate of the inter-section point.

Subroutine YINCPT:

An inter-secting x-coordinate and x and y coordinates of a chosen line are passed and it returns the y-coordinates of the inter-section point.

Subroutine HORDIS:

The x and y coordinates of a chosen line and a point are passed and it returns the horizontal distance between the point and the line.

The flow chart of program II is shown in Fig. 19. Its organisation is similar to Program I. The different subroutines used are described below.

Subroutine ANGLE:

The coordinates of the component are passed into this subroutine and it returns the start and end angles of all circular arc segments.

Subroutine WIDTH:

The current coordinates of the component are passed and it returns the width and the maximum and minimum values of all segments.

Subroutine PITCH:

The current coordinates are passed and it returns the pitch.

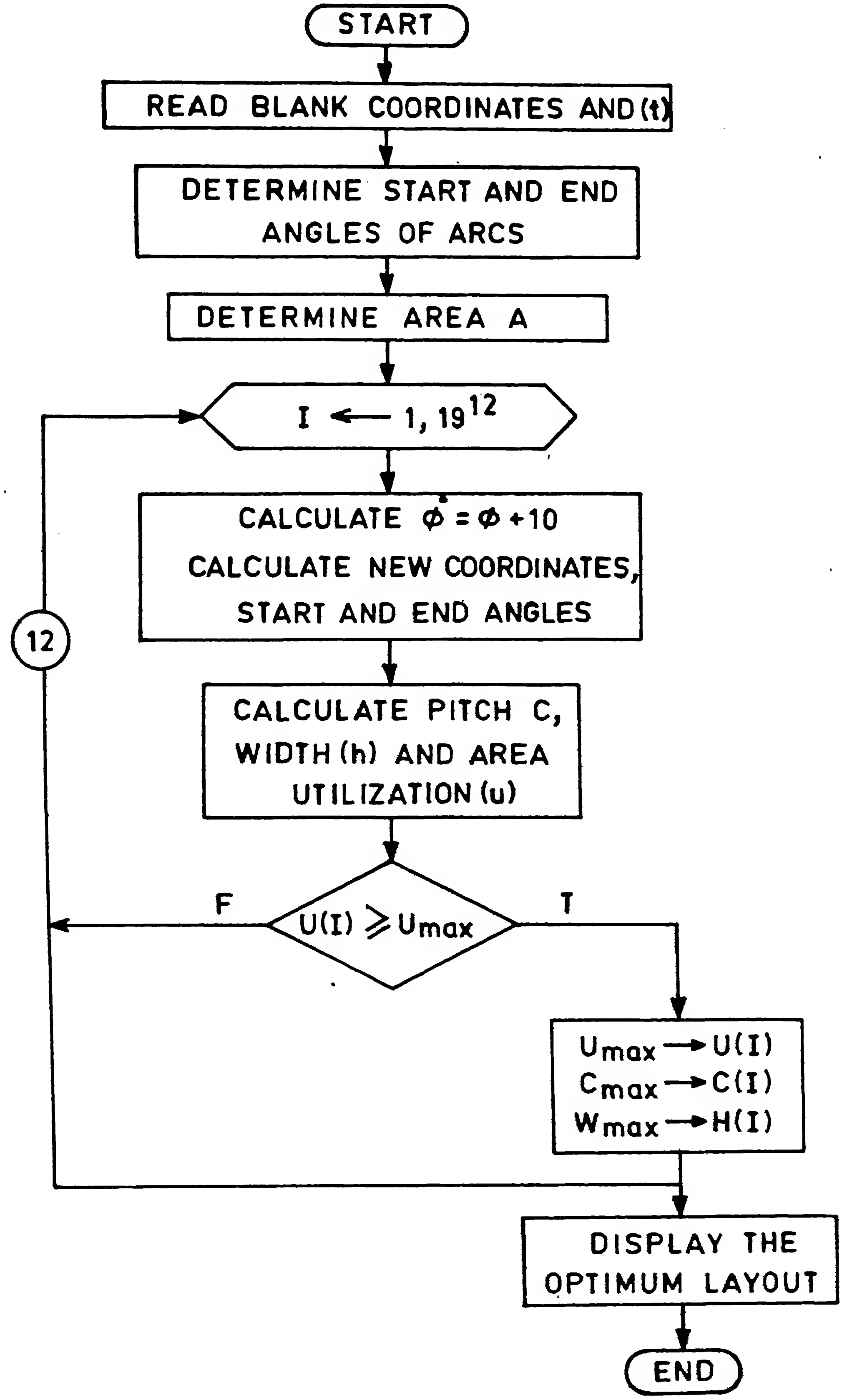


FIG. 19 FLOWCHART OF PROGRAM 2.

Subroutine INTVLS:

The maximum and minimum y-coordinates of two segments is passed and it returns the two intermediate y-coordinates.

Subroutine TEST:

The coordinates and start and end of an arc is passed and it checks whether 90° or 270° fall within the given arc.

Subroutine ANGL1:

The coordinates of an arc and an inter-secting y-coordinate are passed and it returns the number and values of inter-secting x-coordinates.

Subroutine HORDIS:

The x and y coordinates of two selected straight line segments is passed and it returns the maximum horizontal distance between them.

Subroutine HORDCS:

The coordinates of a selected straight line and an arc segment are passed and it returns the maximum horizontal distance between them.

Subroutine HORDIC:

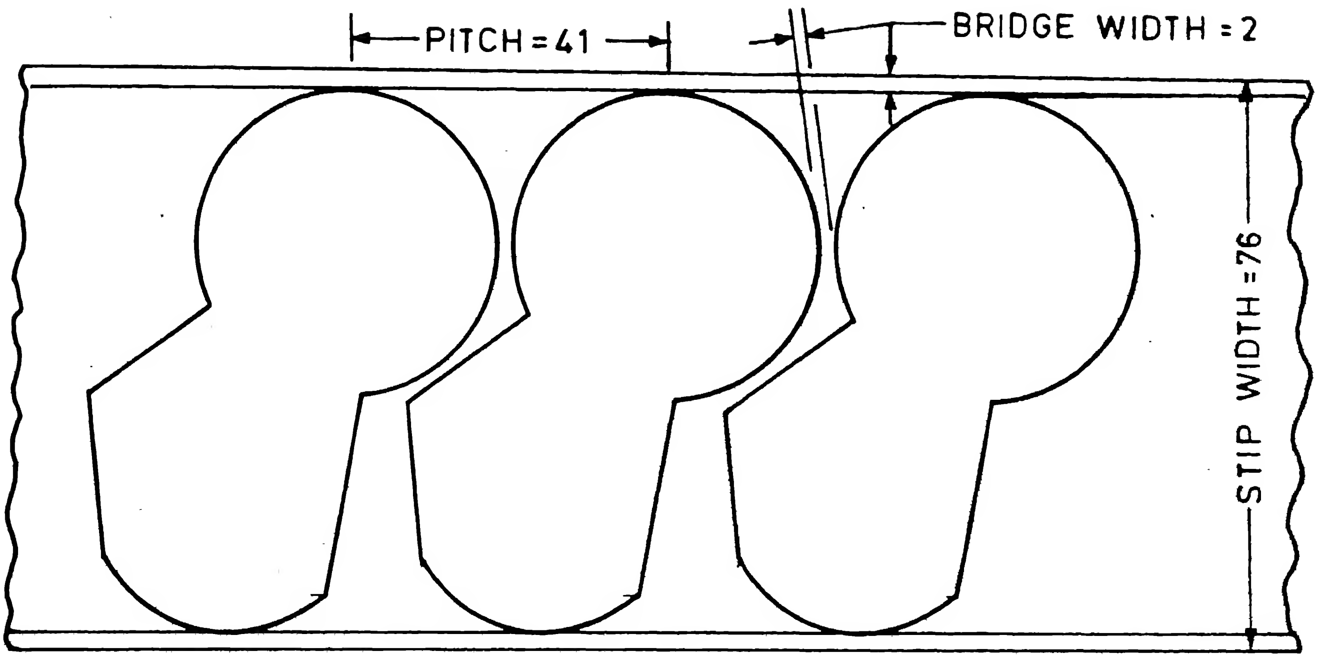
The coordinates of two selected circular arc segments are passed and it returns the maximum horizontal distance between them.

6.2 Typical Examples and Discussion of Results.

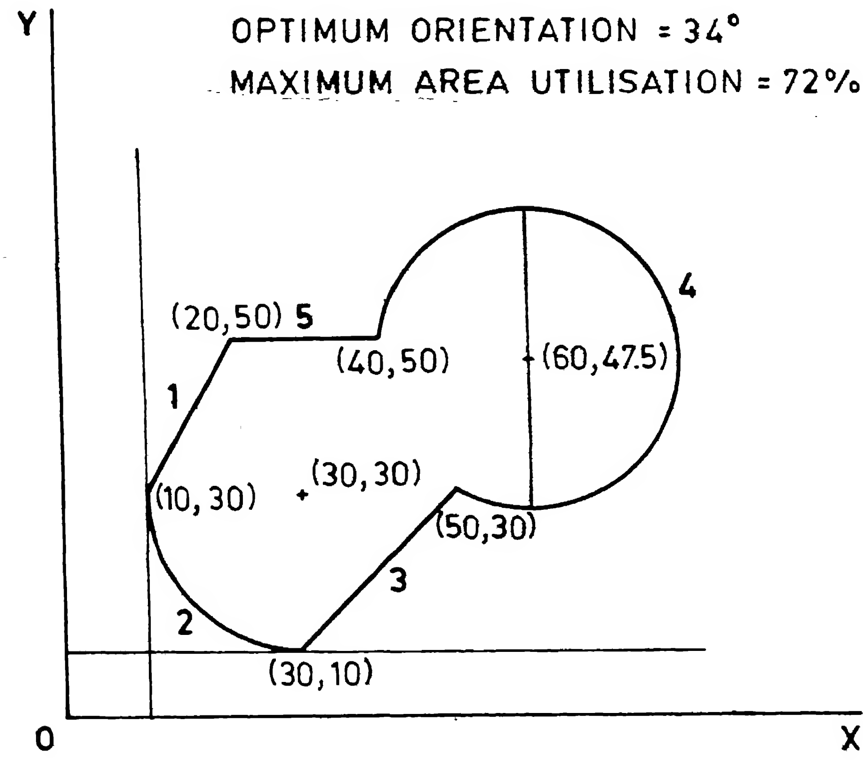
A typical component with circular arcs on its contour and its layout is shown in Fig. 20. It is seen that the single row layout solution gives an area utilisation of 72 percent with an optimum orientation of 34°. It is seen from the area utilisation vs. orientation plot shown in Fig. 21 that the area utilisation increases sharply near the maximum which is due to the particular shape of the component.

The layout of a polygon shaped component with sheet width constraint is shown in Fig. 22. It is seen that the maximum overall area utilisation of 45 percent at a orientation of 80° is rather low and is because of the sheet width constraint.

The photographs of the layout of the above polygon shaped component and the corresponding sectional views of the die assembly are shown as Fig. 23, and Fig. 24.



SINGLE ROW LAYOUT SOLUTION



A COMPONENT WITH CIRCULAR ARCS

FIG. 20 OPTIMUM SINGLE ROW LAYOUT SOLUTION.

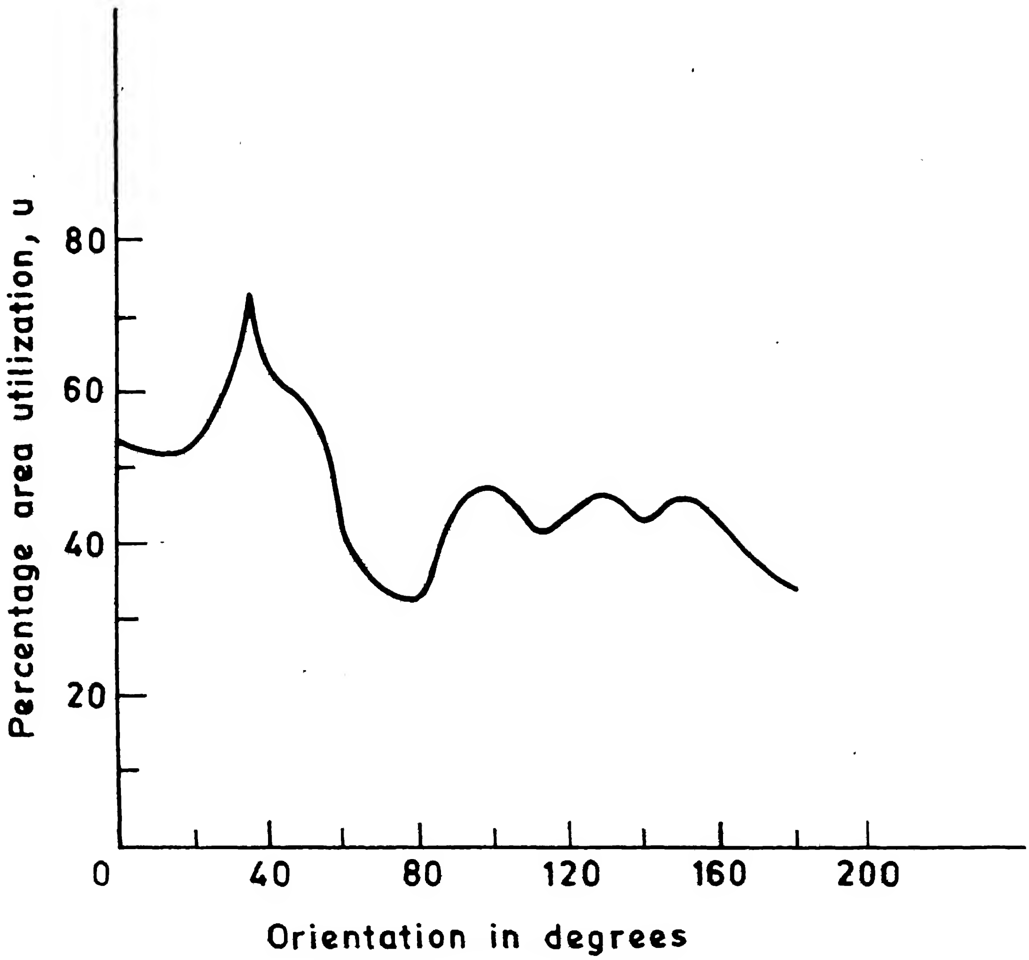


Fig. 21 Variation of area utilization with orientation.

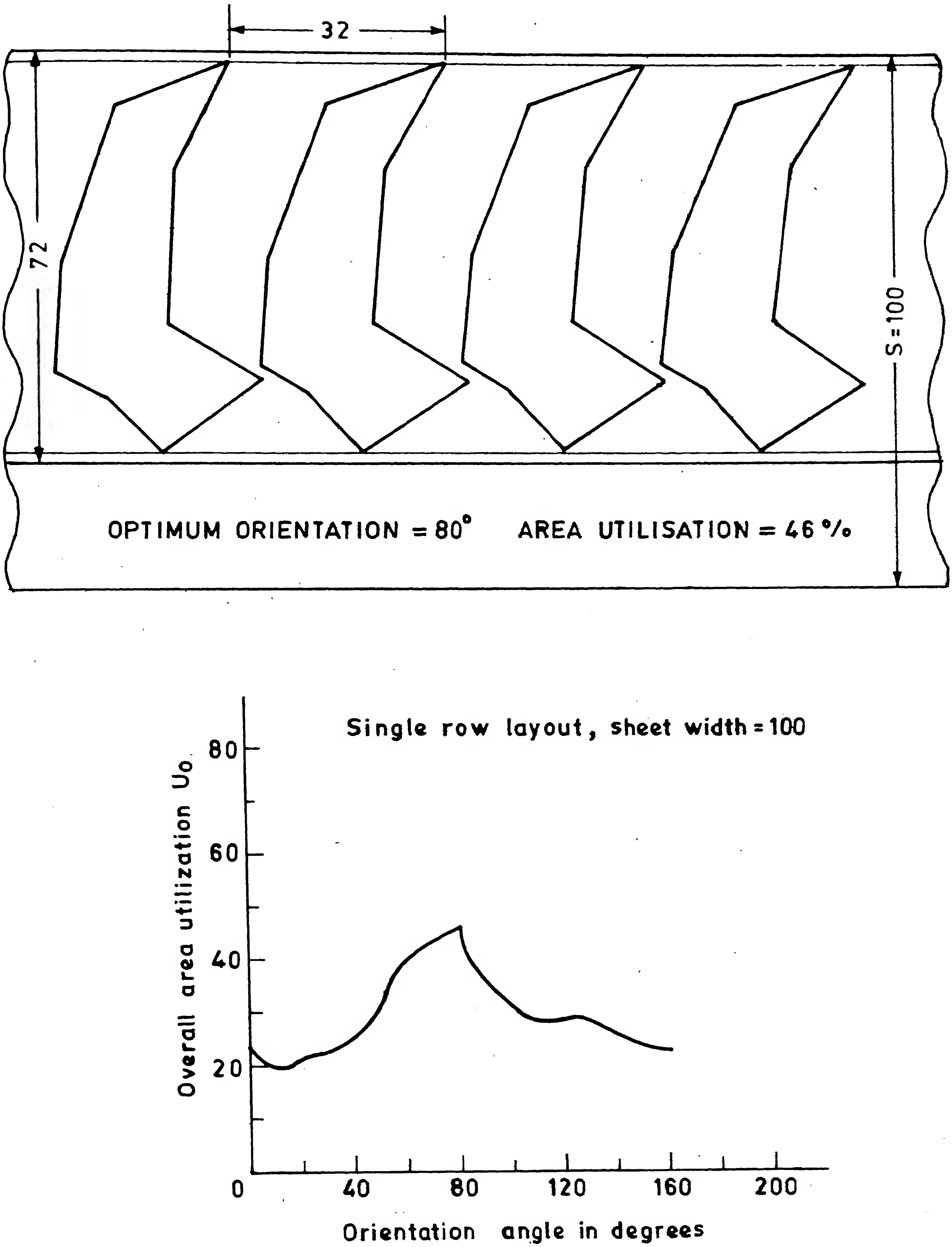
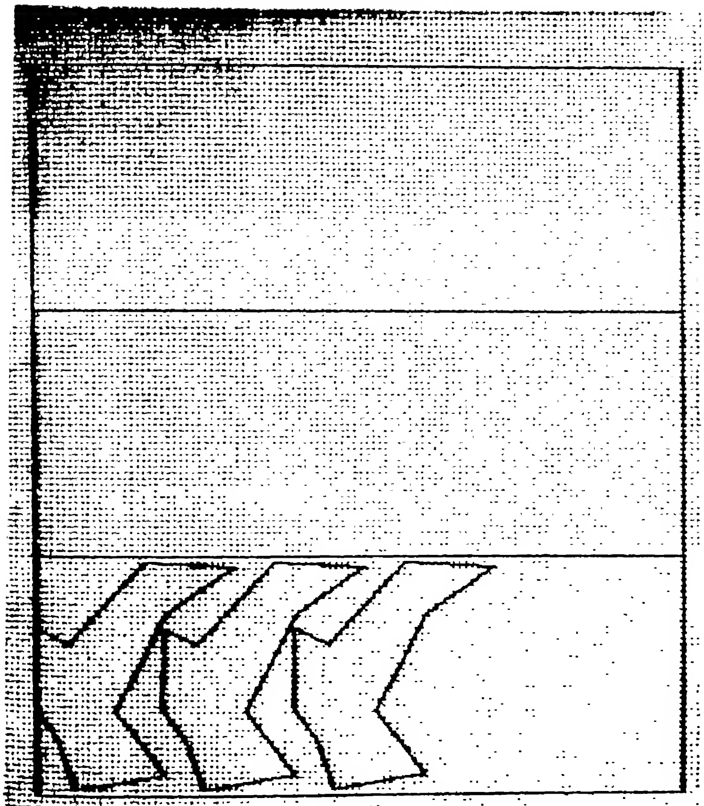
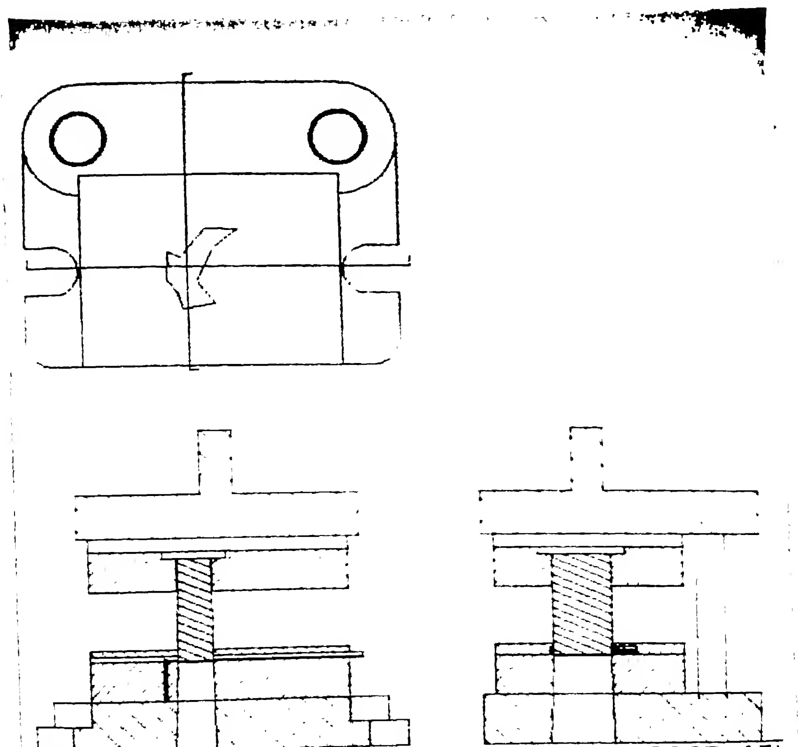


Fig. 22 A single row layout with sheet width constraint.



[illegible] LAYOUT



SECTIONAL ELEVATAION SECTIONAL SIDEVIE

CHAPTER VII

CONCLUSIONS AND SCOPE FOR FURTHER WORK

7.1 Conclusions:

The algorithms proposed for the single-row and pairwise layouts for components represented as a polygon are tested. It is observed that the specific shape of the component determines the orientation for maximum area utilisation. The algorithms of the component with circular arcs as parts of its contour is tested for single-row layout case. The algorithms involved in die design are also tested for a polygon shaped component.

The package implemented for integrated design of strip layout and blanking die (Programme I) enables the die designer to interactively select an optimum layout and a corresponding die design.

7.2 Scope for Further Work:

Further refinements of the layout and die design package developed in this work, can be made by designing all components of the die set, inter-actively with graphical representation of the parts. For pairwise layout, the option of designing a progressive die can be built into the package and compared with the corresponding simple blanking die.

The above package can be implemented for the case of components involving circular area as part of their contours.

A NC programming interface can be linked with the package for machining the punch and die block.

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APPENDIX I

TABLES

Table A: Die thickness per ton of pressure.

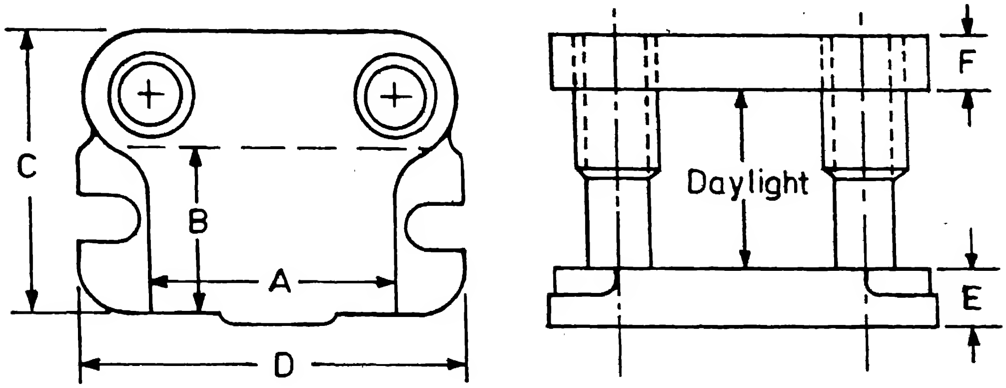
Stock thickness (in.)	Die thickness (in.)+	Stock thickness (in.)	Die thickness, (in.)+
0.01	0.03	0.06	0.15
0.02	0.06	0.07	0.165
0.03	0.085	0.08	0.18
0.04	0.11	0.09	0.19
0.05	0.13	0.10	0.20

\+ For each ton per sq. in. of shear strength.

Table B: Factors for cutting Edges Exceeding 2 Inches.

Cutting perimeter, (in.)	Expansion factor
2 to 3	1.25
3 to 6	1.5
6 to 12	1.75
12 to 20	2.0

Table C: Dimensions of the Die Set

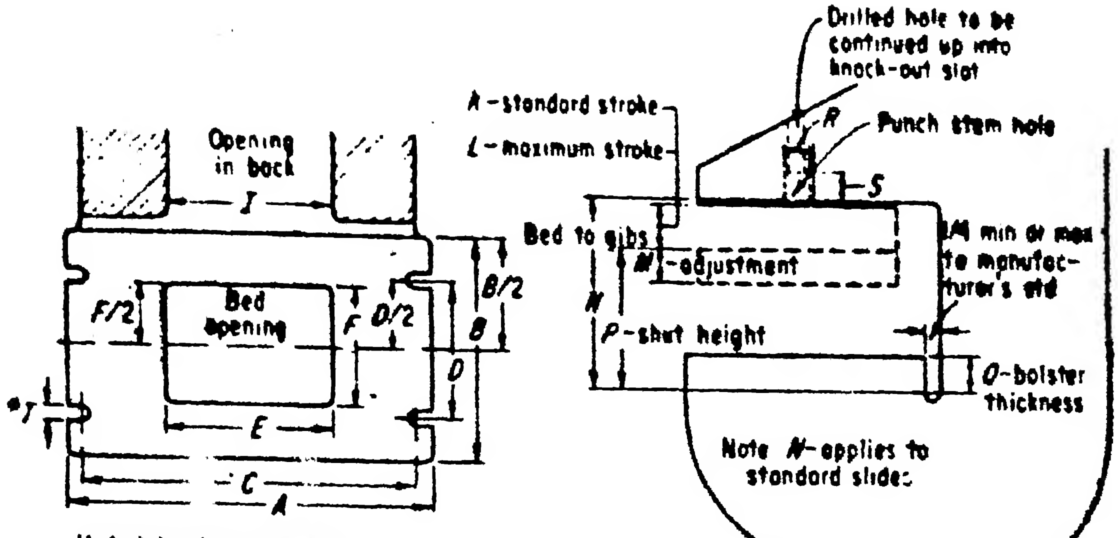


CAST IRON
REAR PILLAR RECTANGULAR DIE SETS

Ref.	Die Space		Approximately			
Cat No.	A	B	C	D	E	F
RR 1	65	50	85	105	25	25
RR 2	75	55	95	115	25	25
RR 3	100	75	125	150	30	25
RR 4	125	100	155	200	30	25
RR 5	125	110	175	200	35	30
RR 6	150	75	118	227	35	30
RR 7	150	110	175	227	35	30
RR 8	200	150	225	290	40	35
RR 9	210	110	175	287	40	35
RR 10	225	175	250	320	45	35
RR 11	235	125	185	320	45	35
RR 12	300	125	190	400	50	40
RR 13	300	150	242	400	45	35
RR 14	300	225	300	400	50	40
RR 15	375	225	300	465	55	45
RR 16	450	200	280	550	60	50
RR 17	450	350	433	550	60	50
RR 18	500	250	340	620	60	50
RR 19	500	300	410	620	60	50
RR 20	600	450	550	700	70	60

all sizes are in m.m.

Table D: Press Dimensions



H—bolster bolt diameter

*Note: mounting holes or slots in press bed, for bolting bolster plate to bed to conform to center-to-center distances on bolster plate

Ton-nage	A	B	C	D	E	F	H	I	K	L	M	N	P	Q	R	S
22	20	12	18	7½	8	5	¾	9	2½	4	2	11¼	8½	2½	1⅝	2⅛
32	24	15	22	9	11	8	¾	11	3	5	2¼	12¾	9½	2½	1⅝	2⅛
45	28	18	25½	10½	14	8	1	13	3	6	2½	14¼	11	3	2⅛	3
60	32	21	29½	12	16	11	1	15	3½	7	2¾	16¾	13	3	2⅜	3
75	36	24	33	18	18	14	1¼	18	4	8	3	19¼	15	3½	2⅝	3
110	42	27	39	18	21	15	1¼	21	5	10	3½	23¼	18	4	3⅛	3
150	50	30	47	18	21	17	1¼	24	6	12	4	28¼	22	4½	3⅛	3
200	58	34	55	18	27	21	1¼	27	8	12	4½	32¼	24	5	3⅛	3

JIC standard dimensions for OBI presses.